01 FALL 2013

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ASME GLOBAL DEVELOPMENT REVIEW

COOKING LUNCH IN MALI Clean cookstoves in places like rural Mali are in demand, but it's not just about the technology. The use of ethnographic analysis uncovers barriers to adoption and yields guidelines for cookstove design. Page 8.

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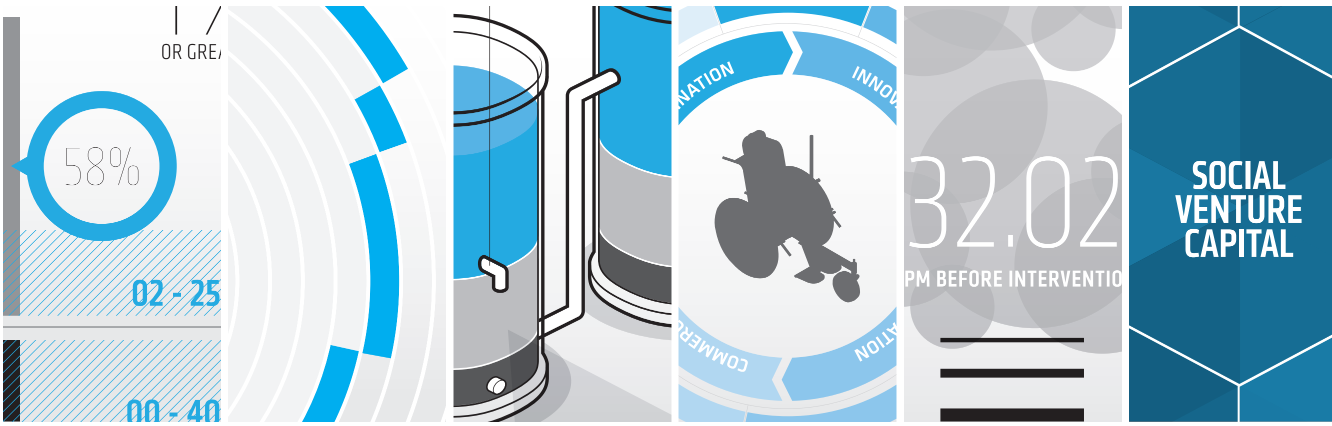
ASME GLOBAL DEVELOPMENT REVIEW



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ABOUT DEMAND: Through the lens of engineering DEMAND, ASME's global development review, showcases effective strategies and innovative solutions at the intersection of technology and global development. The case studies examine areas from access to basic needs and product development to improving technical literacy and failure analysis. Our aim is to challenge the existing and upcoming corps of engineers and practitioners to re-invent approaches, methods and assumptions to create more effective and sustainable solutions.

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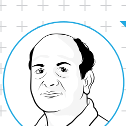

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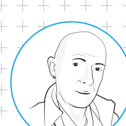

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FROM THE EDITORS

WELCOME TO THE PREMIER issue of DEMAND, ASME's global development review. It was launched by "ASME's Engineering for Global Development committee" to help meet the needs of individuals and organizations working at the intersection of technology and global development. With DEMAND, we bring you a unique mix of case studies, stories and original reports representing the diverse challenges and solutions emerging in the field. In this issue and in future issues we tackle thematic areas in global development and include applications from product design and technical performance to distribution and evaluation models. Our mission is to promote shared learning through thoughtful, in-depth examinations of the technical, programmatic and community challenges faced by nonprofits, socially responsible businesses, academic programs and government agencies engaged in global development.

DEMAND is written for and by social innovators in the nonprofit, academic, and business sectors who are involved in developing and delivering appropriate, technology-based solutions to benefit the environment, public health, and infrastructure.

In this first issue, our authors consider broader system contexts while demonstrating the application of engineering means and methods in the field. They have captured best practices and innovations in the sector. The cases cover a wide range of subjects, but the unifying thread is the unique viewpoint—through an engineering lens—and a demonstration of stakeholder-driven innovation as a model for solving the most pressing challenges of disadvantaged communities.

DEMAND was created and published by ASME in collaboration with *Mechanical Engineering* magazine and reporting from EngineeringforChange.org. All the case studies in this publication undergo review both by an independent editorial review board and by ASME editors. Our goal is to deliver high-quality, accessible and timely information. Our hope is to excite the greater engineering community to develop solutions that are in demand.

ON THE COVER
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ASME GLOBAL DEVELOPMENT REVIEW
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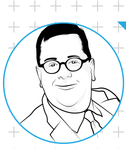

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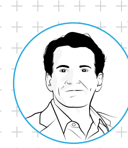

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COUNTING HEADS

01

Field surveys, the longstanding tool for evaluating the success of a development project, can be prone to biases. Can the use of specially installed remote-monitoring sensors be a tool for gathering more data?

In 2010, brightly colored latrines began popping up in and around Jakarta, Indonesia. The latrines were perhaps the most visible sign of global relief and development agency, Mercy Corps and its recent efforts to conduct a water, sanitation and hygiene program in the area. ¶ In Jakarta, as in much of the world, clean water is a luxury, and many of its 10 million inhabitants do without. As a result, diarrhea is a major cause of child malnutrition and mortality in greater Jakarta. Clearly, access to a healthy water supply and sanitation services is a critical step toward preventing diarrhea and other diseases.

One program from Mercy Corps, called RW Siaga Plus+, installed latrines and hand washing stations at a number of sites across greater Jakarta. It also included an extensive behavior-change campaign to encourage the use of the latrines and to improve hand washing practices. The initiative, as we will discuss later, proved to be quite successful on several fronts.

RW Siaga Plus+ was formed around an existing Ministry of Health program, RW Siaga, which was a comprehensive community-based health program focused on developing the capacity of communities to prevent and respond to health problems, disasters and emergencies. RW Siaga Plus+ was

Traditional evaluation methods sometimes have overestimated adoption rates.

designed to integrate access to water and sanitation infrastructure into this foundational program.

The program was also designed to work toward one of Mercy Corps Indonesia's key objectives: creating healthy physical environments in poor urban settlements by increasing access to clean water supplies and improved sanitation. The aim was to reduce the incidence of malnutrition within those communities,

THE OBJECTIVES OF THIS CASE STUDY WERE TO:

- Compare and contrast the findings from two complementary approaches to field evaluations of a water, sanitation and hygiene program in greater Jakarta.
- Highlight the complementary nature of monitoring instrumentation and traditional survey methods.
- Assess how instrumentation might provide important program feedback not normally available with traditional survey tools.
- Assess the potential impact of sensor-acquired data on traditional survey tools.

particularly among children under the age of five, by reducing the risk of infectious disease through improved water and sanitation conditions, and hygiene and nutrition behaviors.

Two studies of RW Siaga Plus+'s effectiveness incorporated two sets of field data: Traditional survey-intensive evaluation methods—including household surveys conducted by program staff as part of their monitoring and evaluation processes—and remote monitoring using special low-cost, low-power sensors.

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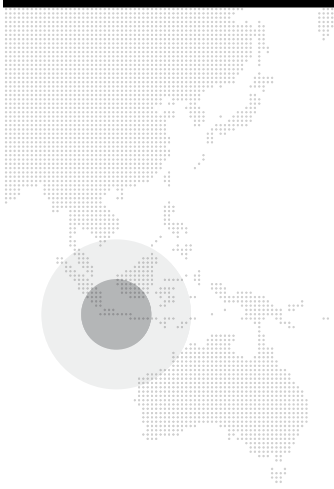
JAKARTA, INDONESIA



The use of sensors in conjunction with the findings of the traditional household surveys and qualitative methods is a new approach to an old problem. Until now, organizations like Mercy Corps have largely gauged the success of programs by relying on direct feedback from members of the community. But such traditional evaluation methods can sometimes overestimate adoption rates due to a variety of factors, among them the tendency of interviewees to be selectively forgetful, and the wish to be helpful; the possibility of field staff reporting “on the behalf of the interviewees”; interviewee fatigue; and the failure to include survey questions which turn out to be critical in the analysis stage. This phenomenon is hardly new. It has been demonstrated in a number of scenarios, including determinations of poor correlation between observations and self-reported recall of water storage, hand-washing and defecation practices[1],[2].

With this in mind, the team set out to see if the sensors could determine whether or not survey results were reflecting actual adoption behavior rate of the RW Siaga Plus+ program. Our goal was to evaluate if instrumented monitoring could gather data on adoption behavior, and compare it to qualitative tools and household surveys. By using these sensors, real-time data can be inexpensively logged and analyzed to study recipient behavior in the intervention at hand. Data from sensors can also be used in conjunction with other data sources to understand programmatic, social, economic and seasonal changes that may influence the quality of the system in question. Additionally, behavioral patterns, such as how and when a system is being used, can be analyzed to help develop a sustainable system by integrating the user’s behaviors into the design and modification of the system.

Working in conjunction with the Portland-based Stevens Water Monitoring Inc., the Sustainable Water, Energy and Environmental Technologies Laboratory at Portland State University developed two types of low-power, low-cost, user-friendly hardware instruments to measure the actual use of the program's water and sanitation facilities (as well as another Mercy Corps-helmed program involving cookstoves in Haiti).

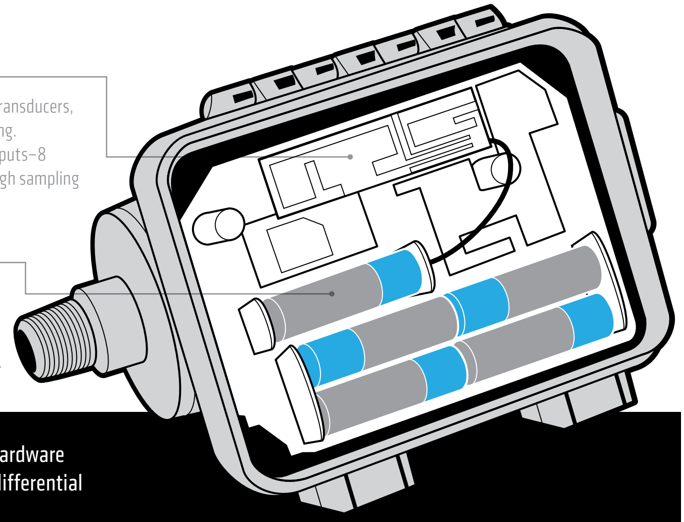


FIG 1: SWEETSense hardware platform applied to differential pressure flowmeter

REMOTE SENSING MONITORING

The sensing technology developed by Portland State’s SWEETLab (which is overseen by co-author Evan Thomas) is called SWEETSense, see Figure 1. The lab is working with various partners to implement the sensors in different scenarios to assess their potential applications. The SWEETSense technology, it is believed, has the potential to provide objective, quantitative and continuous operational data on the usage and performance of programs across a range of sectors and communities.

In all instances, the SWEETSense hardware platform combines commercially available front-end sensors, selected for water treatment, cookstove, sanitation and infrastructure and other applications with a comparator circuit board that samples these sensors at a reasonably high rate. The comparator boards monitor the sensors for trigger threshold events that start and end periodic local data logging. The comparators sample the sensors frequently, and the output is fed into a low-power microcomputer chip where the relative time that the parameter change occurs is logged. Logging continues until the parameter returns to a predetermined baseline. The stored events are coded to reduce the amount of data, and thereby the amount of energy required for transmission. An on-board SD card allows for local backup logging, as well as logging when cell phone towers are disabled or out of range.

When applied to water flow measurements, a transducer comparator examines the reported water pressure data and waits for a change, indicating, perhaps, that a tap has been opened. When a sudden drop in water pressure is observed, the system starts logging the pressure readings until the user closes the tap. Closing the tap will cause a so-called water hammer effect, resulting in spiking pressure readings. That pressure spike is a signal to discontinue data logging and return to low power sampling. Two pressure transducers, or a single differential pressure transducer, across an orifice or pipe diameter difference allows correlation of differential pressure readings to volumetric flowrate.

At least once a day, the comparator board relays logged data events either to another parent board or directly to the Internet via cellular networks or WiFi. Data processing is enabled on an Internet-based software program,

OTHER APPLICATIONS OF SENSORS IN GLOBAL DEVELOPMENT

- Indoor air-pollution instrumentation using a particle monitor conducted at the University of California at Berkeley and the associated Berkeley Air Monitoring Group[3].
- A stove-temperature sensor developed by the University of California at Berkeley
- A hand-pump motion monitor with remote reporting developed at the University of Oxford[4].
- A passive latrine use monitor for sanitation studies developed by the University of California at Berkeley and the London School of Hygiene and Tropical Medicine[5].

where the primary algorithms are stored. The Internet-based program also contains manually and automatically updated calibration files that are periodically and automatically relayed back to the local sensor boards.

The data is integrated with www.sweetdata.org, an online database hosted on Amazon Elastic Compute Cloud. First, the sensor boards deliver data on a reconfigurable period. The Internet-based protocols then process the raw data into summary statistics and aggregate these results with the database to present to the front-end user summary data on frequency of use and performance of each sensor and the technology it is monitoring.

Most commonly used data-acquisition systems require multiple components—including sensors, microprocessors, loggers, radios, antennas, and a power supply—that are packaged and sold separately, thereby increasing cost, complexity and power consumption. Additionally, many existing systems require specialized software to collect and analyze the data.

By contrast, the SWEETsense hardware platform's architecture is significantly lower in cost and more accessible to the end-user than a similarly functional collection of off-the-shelf components. The platform is fully integrated and includes front-end sensors, processing hardware, radio and power supplies. It is designed to maximize the value of the data and minimize power consumption; indeed, high-resolution data logging is powered by common AA batteries.

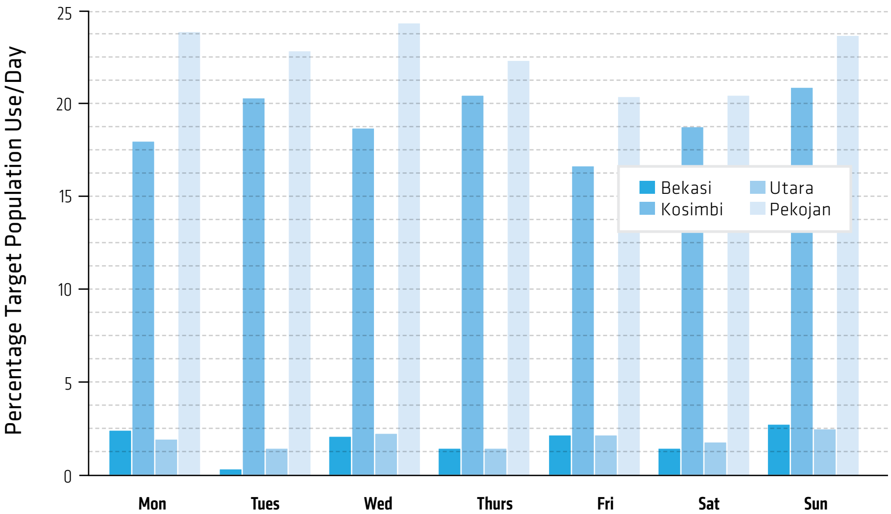


FIG 2: Percentage Population Latrine Use Per Day (Instrument data analysis)

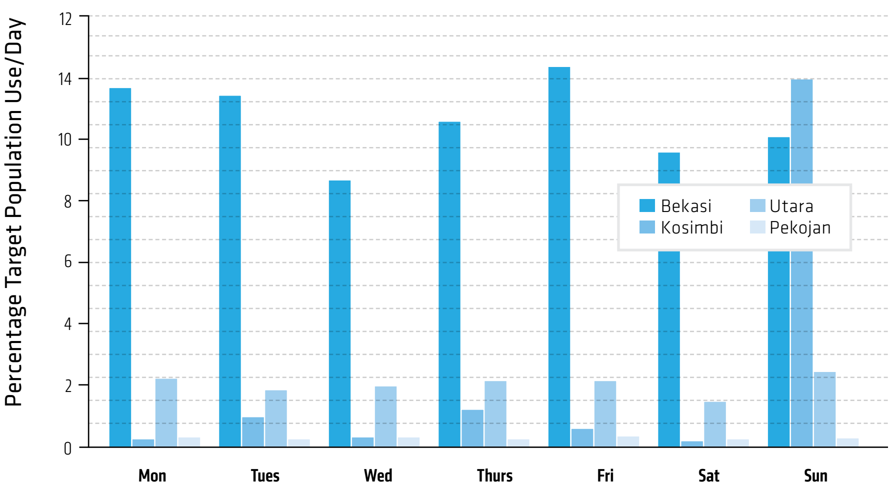


FIG 3: Target Population Water Use Per Day (Instrument data analysis)

MONITORING PROGRAM

RW Siaga Plus+ was implemented between September 2009 and September 2011 in 16 poor urban neighborhoods—known as *rukun warga* in the Indonesian language—in the Duri Utara, Duri Kosamb and Bekasi *kelurahan* or subdistricts in West Jakarta and the Margahayu subdistrict in the city of Bekasi.

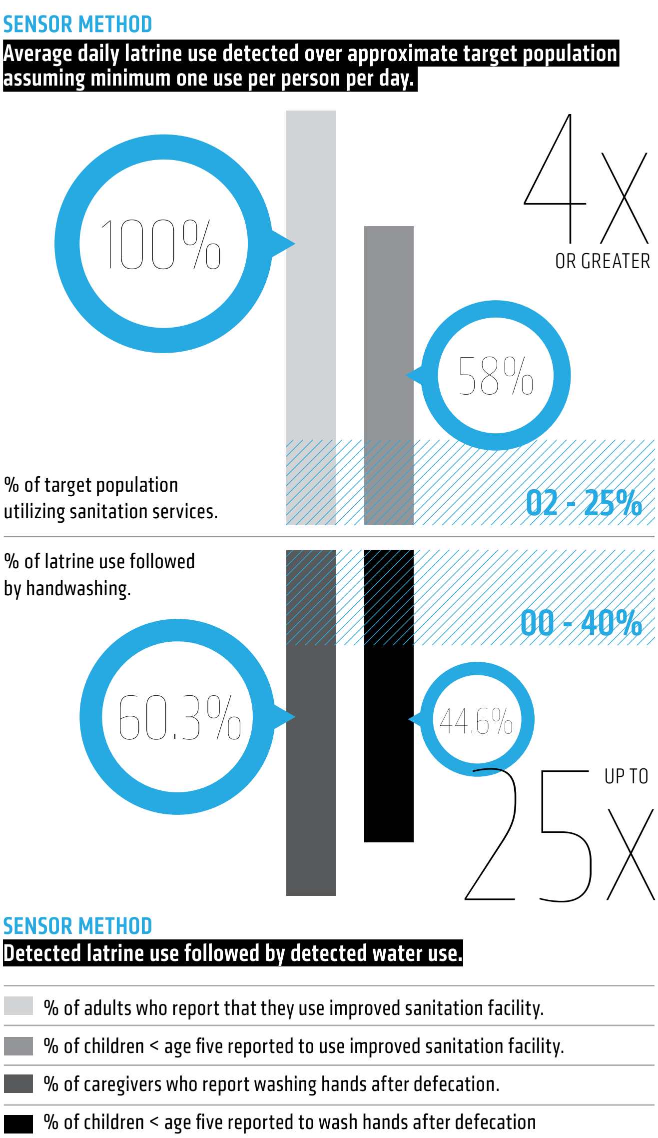
Before embarking on the two-year project, Mercy Corps projected that:

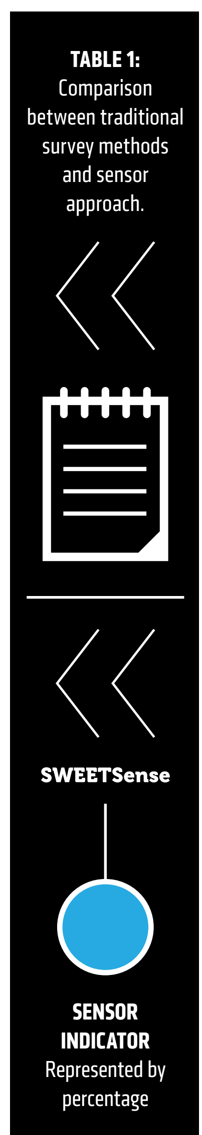
- 1,400 households (approximately 7,000 individuals) would have access to and use the improved sanitation facilities.
- 30,000 households would have access to safe water.
- 30,000 caregivers of children under the age of five would practice appropriate hygiene and nutrition behaviors.
- All targeted communities would take responsibility for at least one component of the RW Siaga+ program—such as regular cleaning and maintenance of the facilities and community health promotion—during the second year of RW Siaga Plus+, in preparation for replicating the program's model after its completion.

At the end of the RW Siaga Plus+ program, Mercy Corps conducted a public-health evaluation using a statistically significant household survey sample, focus group discussions and interviews to determine the program's effectiveness toward achieving behavior changes and reaching overall program targets. They found a high degree of self-reported compliance with some behavioral changes. But knowing that traditional survey methods can sometimes have data bias, Mercy Corps asked us to see if sensors could be used to gather longer term quantitative insights into sanitation practices.

In September 2012, a year after the official close of the program, both latrine motion-detectors and the hand-washing sensors were installed in four locations among the 16 neighborhoods targeted in the study. The flowmeters were installed on pipelines providing water from elevated tanks to hand-washing stations and in-latrine bucket filling taps. The latrine monitors were co-located with the flowmeters and monitored door openings and closings at each stall, as well as motion in one of the four available stalls. Each sensor was independent of the others.

All data analysis was conducted exclusively online, with each sensor's reported data being analyzed independently using a validated analysis algorithm. The flowmeters were calibrated to the pressures at the installation location. Otherwise, all sensors of the same type were analyzed in an identical manner. These algorithms generated date- and time-stamped event tables.





All eight of the sensors—two per site at four sites—operated continuously for at least four months. However, the sensor batteries were consumed at varying rates and other factors, such as humidity or cellular network connectivity, contributed to a varying number of data days reported. These variations were compensated for during the analysis by considering average use calculations only during the period of time data reported. Therefore, while one sensor might have reported 100 days of data, and another 150 days, each sensor was averaged for its own reporting period, yielding results that could be directly compared.

In order to compare the public health monitoring and evaluation survey data collected to the sensor data, the analysis considered the target household beneficiary population in each of the four regions, divided by the number of sites, then multiplied by four, the average household size in Jakarta to get an average target population at each site. For the latrine monitor, this was further reduced by 3/4 to account for the sensor monitoring only one of four stalls. The first stall accessed through the entry to the latrine building was instrumented, under the assumption that this would be the most highly trafficked of the stalls. The analysis then assumed that each use represented a unique individual in the target population.

What's more, flowmeters did not distinguish between taps installed inside latrines for flushing versus outside for hand washing and other uses. This likely biased results towards showing greater hand-washing compliance than what actually happened on the ground.

FIELD SURVEYS VS. MONITORING DATA

The RW Siaga Plus+ program conducted a baseline survey of 460 households in January and February 2010, a mid-term evaluation in January 2011, and an endline survey of 500 households primarily between May and September 2011. The final evaluation was conducted in Jakarta and Bekasi September 6 through 16, 2011, with data collected from all four subdistricts where the program was implemented. The purpose of the final evaluation was to asses the overall RW Siaga Plus+ program's results and impacts

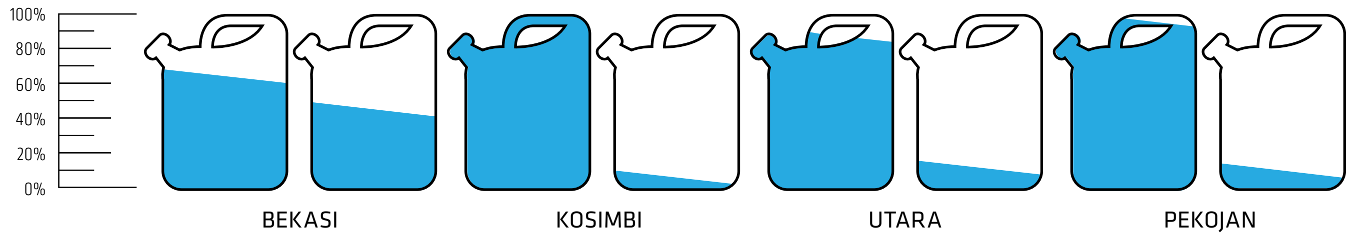


FIG 4: Comparative Use of Latrines and Water — left bottle = latrine use only right bottle = water use after latirne use

on the community and to document the lessons learned from program interventions.

When comparing baseline to endline data the program appeared to have had a significant impact on changing behaviors in the 16 communities in key targeted indicators. Hand washing at critical times increased by 6,367 percent in adults and by 556 percent among children. Other findings showed that reported open defecation among children decreased by 37 percent, and that the incidence of reported diarrhea in children aged 0-5 also reportedly dropped by 35 percent. It's important to note that all of these were self-reported behaviors of survey respondents on behalf of themselves or their children. All behavior-related questions were asked as open-ended questions, with some questions allowing for multiple responses.

Analysis of latrine and water usage data from the SWEETSense instruments at the four sites was conducted in March 2013. We found that there was a high degree of variation between sites. Additionally, there are clear differences from site to site on the types of services being used see Figure 2 and Figure 3.

For example, latrine use in Pekojan is significantly higher than the other sites, while the water use in Bekasi is significantly higher than others. One thing to note here is that the Bekasi site was installed a year or more before the other sites and is located in a less densely populated area of greater Jakarta, so it is possible, though not provable at this point, that Mercy Corps was more effective in encouraging hand-washing compliance in Bekasi than at the other sites.

In terms of comparing the household survey data to the sensor monitoring, a precise comparison is not possible, although we can calculate a rough approximation using the available data see chart on page 5. We can compare the motion detection data for the latrine stalls to survey results for latrine use, and compare actual water usage following latrine use obtained via sensor monitoring to self-reports of hand washing after latrine use. In general, we found that the sensor analysis showed both significantly less use of latrine facilities and significantly less water use for hand washing after latrine use than reported by the endline surveys, see Figure 4. To take one example, while the endline survey found that 60.3 percent of caregivers washed their hands after using the latrine, analysis of the sensor data detected latrine use followed by water use between 0 and 40 percent of the time.

Survey data found a range of 0 to 35% of using public latrines, with a reported use of 0 to 15% of use of Mercy Corps constructed Public Latrines. Similar data was found from the sensors with approximately 2 to 25 percent of the targeted population using Mercy Corps' constructed public latrines, higher than reported in the surveys. Of those 0 to 40 percent appeared to be washing their hands after latrine use at the four respective facilities as indicated by hand-washing tap usage—significantly less than was reported at endline. However, the sensor's are only looking at behavior at the monitored latrines and its not known if this is representative of hand washing practices after other type of latrine use, whereas the endline survey looked at all household's hand washing practices.

This information by itself is valuable in program evaluation as the long-term effectiveness of water and sanitation programming and associated behavior change messaging interventions is often unknown. Combining this kind of data collection with traditional evaluation methods opens us up lots of possibilities, and deeper understanding of what works. The remaining question—is the behavior at these latrines an indicator of overall practices or something different?—is not something a sensor alone can answer. However, an effective behavior change research or evaluation strategy would show whether behaviors are consistently adopted, regardless of type and location of latrine use.

SUSTAINING CHANGE

We also recognize that sustaining long-term behavioral changes is uncertain. The methods employed in the RW Siaga Plus+ program are effective for raising awareness of desired behaviors and for bringing about immediate changes in behavior. However,

> We found that sensor analysis showed comparable use of public latrines and less use of water at taps associated with hand washing after latrine use compared to endline survey data.

research demonstrates that reinforcement of positive behaviors is critical if change is to be sustained over the long term, particularly for hand-washing behaviors where the goal is to prevent incidence of diarrhea[5]. Still, the program's emphasis on infrastructure to support positive behaviors, such as hand-washing stations and increased availability of community latrines, increases the likelihood of sustainability, particularly for reducing open defecation and the use of improved latrines.

Data from the sensors can potentially have multiple applications. The data can be analyzed and compared to secondary data sources such as social surveys, finances, commodity prices, rainfall, school and healthcare facility attendance, or work schedules to better understand user behavior. Other comparisons can be made between implementation strategies such as particular educational materials or the use of community health workers to disseminate the technology. Results can also be monitored with more frequency than traditional survey methods, allowing for more adjustment of program interventions. With this data, systems and implementation strategies can be designed more effectively to accommodate a user's needs and desires.

Instrumented monitoring systems may be an effective method to improve data collection and thereby program quality and impact within global health programs. Mercy Corps, like other development organizations, invests significant resources in water and sanitation infrastructure and behavior change programs. It also invests in monitoring and evaluation staff time, though it remains aware that survey data can be biased towards showing success and most often relies on self-reported data. By incorporating instrumentation with remote data access, programs can monitor results over time, rather than relying on isolated survey response, and more directly measure behavior and reduce self-reporting bias. This can now be done at a significantly lower per-sample cost given the availability of sensor technology.

Remote sensors can capture usage data, but they don't tell the whole story. It is important to triangulate these findings with other sources of information, and qualitative data as well, to better understand behaviors and attitudes related to these practices.

But use of remote monitoring sensors coupled with traditional monitoring and evaluation methods may work to improve overall programming in the long run. Combining both methods throughout the intervention period and beyond the end of the program could potentially contribute to greater understanding of the effectiveness of the projects and ensure that not only targeted program indicators are met but that the end results—abundant clean water, improved hygiene, reduced infectious disease rates and malnutrition, especially in young children—are sustained.

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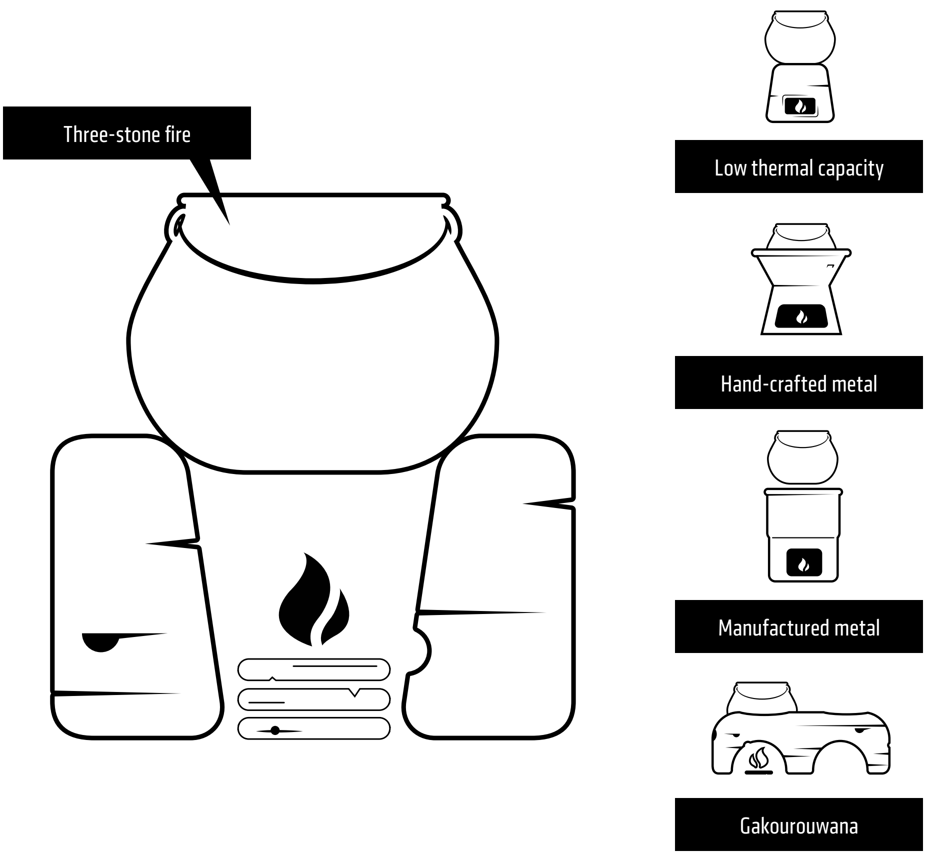
CASE STUDY

CLEARING THE AIR OVER COOKSTOVES

02

Improved cookstoves won't save fuel or reduce pollution if they can't be incorporated into daily life.



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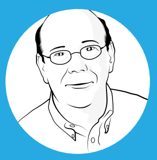


KENNETH M. BRYDEN is associate professor of mechanical engineering at Iowa State University. He is president of Engineers for Technical and Humanitarian Opportunities for Service, a NGO focused on the issues of household energy in the developing world.

NANA KENIEBA, MALI

Every morning across the globe, small open fires are started and tended by women as part of a daily routine. The fires are essential to households, as they provide hot water and cooked meals. The smell of the smoke from those open fires, in fact, is woven into the texture of life in much of the developing world.

But these open fires require wood or charcoal for fuel and are implicated in deforestation and the smoke pollutes the skies and cause respiratory illnesses. For the past half-century, public and private organizations have developed new and improved cookstoves and have distributed them to nearly 830 million people.[1] Some of these units have been more efficient and less polluting wood stoves; others use gas or liquid fuels to displace biomass.

In spite of these efforts, however, the number of people using open fires is expected to remain unchanged over the next 15 years.[2] One reason for this is because the population is growing faster than the number of cookstoves, and when stoves break people often go back to cooking over open fires.

Ultimately, the problem is one of adoption as well: the people for whom improved cookstoves are designed often don't use them the way that the engineers had in mind. Sometimes, they don't use them at all.

Our experiences throughout many of villages across Africa, Asia, and the Americas confirm the largely anecdotal evidence that improved stoves are underutilized. Users tend to adopt improved cookstoves as additional cooking devices rather than replacing open fires.[3] This practice, commonly referred to as "stove stacking," occurs when users retain multiple cookstoves, each for a specific purpose. Much the way that a Western family might have a gas stove, a microwave oven, a toaster, a waffle iron, and a slow cooker and use each for different, specific tasks, a family in the developing world might see an improved cookstove not as a replacement for an open fire but a supplement to it.

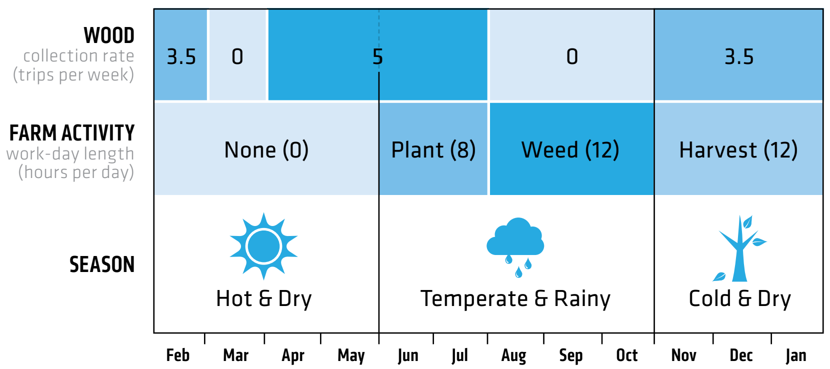
The developers and philanthropists who provide well engineered clean-burning stoves often overlook such cultural considerations. Designing a fuel-efficient, low-emission stove is an engineering challenge, but engineers must also understand local needs and preferences. No matter how efficient an improved stove may be, it won't reduce fuel consumption or improve public health if it's not used.

A growing body of research indicates that cookstove use and impact are shaped by many factors, from culture and demographics to climate, diet and local infrastructure. Yet most cookstove studies have focused narrowly on the effect of materials and construction on stove performance and emissions. Comparatively little attention has been paid to developing design criteria and constraints informed by local needs and preferences.

The place of cookstoves in routines of everyday life—that is, the experiences of cookstove users—is generally overlooked yet it is essential to understand the design needs. Cookstove technologies shouldn't just be engineered for efficiency, but also for impact.

Addressing this challenge begins with in-depth field study. For our part, we traveled to an isolated rural village in sub-Saharan Africa to examine how people there use various cooking technologies. We discovered that the impact of improved cookstoves in this village

FIG 1: Farming activity and wood collections by season[8]



was minimal, but we also developed some guidelines that might improve the penetration of introduced cooking technology in the future.

Further, we tested and measured fuel use. We discovered that 98 percent of all energy used in the village goes to domestic needs, particularly cooking and space heating. Of that energy, 94 percent comes from wood, of which three-quarters is burned in domestic cookstoves. The village annually consumes 234 metric tons of wood.[4]

VILLAGE LIFE

We made four visits to Nana Kenieba, a village in southern Mali, between May 2009 and December 2010 to examine the human, natural, and infrastructural factors that characterize the dynamics of village energy supply and use.[5] Nana Kenieba is located within the Sahel, a transition region between the Sahara desert and Africa's mid-continental forests. Mali ranks 160th out of 169 countries on the United Nation's Human Development Index, which measures life expectancy, educational attainment and income.[6] Mali also has the world's sixth-worst mortality rate for children under five years old attributed to water and air pollution.[7]

All 60 families in the village live on subsistence agriculture. Seasons define rural life and economics, including agricultural activities, wood harvesting and other duties. During the rainy season, for instance, 10 percent of the village's 770 residents live outside the village proper, in small camps adjacent to their farmland, see Figure 1.

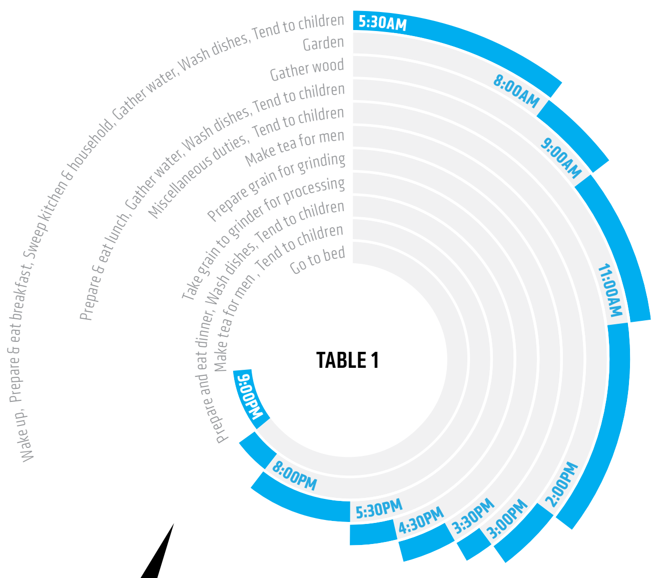
Connection to the world beyond the village is difficult. There is no access to the electrical grid and travel along the dirt roads is by foot, bicycle or the small bus that departs daily for the market town 35 kilometers away. Any goods not available in the village can be sourced from the market, however, many of the goods used in the village are supplied by local artisans, including blacksmiths, bakers, tailors, carpenters, furniture makers, brick makers, potters and basket makers.

Homes are commonly built from uncompressed earthen blocks and thatch roofs. Kitchens, which are constructed from mud-daubed wood lattice, are separate structures

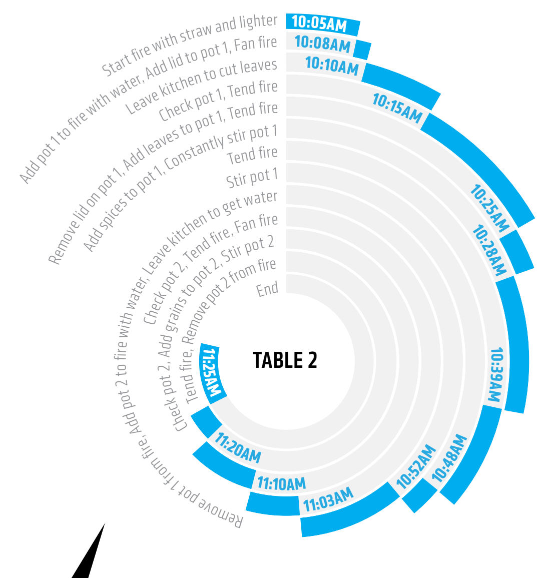
Cookstove technologies shouldn't just be engineered for efficiency, but also for impact.

from the main living space. Families are often polygamous, with several women exchanging familial cooking duties every few days. It's common for women within the same family to have separate kitchens and cookstoves.

We visited five families, ranging from small (fewer than seven members) to large (more than 22 members). Our study encompassed several different methods, from direct observation and participation with the



Typical daily activities for an adult woman



Example time-series data for cooking lunch

cookstove users that enabled us to identify factors that may influence cookstove use and impact, to surveys and interviews that allowed us to gather demographic data and information on the types and numbers of cookstoves used, how each stove was used and whether cooking practices varied between seasons.

The typical daily activities for an adult woman leave little free time to pursue leisure activities or wage-earning ventures, see Table 1. Most socializing occurs when gathering wood, collecting water or waiting in line for the diesel-powered grain grinder. Due to cultural practices, only married women with children perform cooking duties; unmarried women and women without children do not cook.

More detailed data on the cooking process were captured using activity diagrams and minute-by-minute time-series accounts of each cooking task, see Table 2. These data show how women completed multiple activities while cooking, such as preparing ingredients, tending to children, cutting tinder and shelling peanuts. Such parallel activities are often completed outside the kitchen, drawing the cook's attention away from the fire for periods as long as up to 15 minutes.

To keep an unattended fire from smoldering, women in the village prefer to stoke a fire with large amounts of wood. Improved cookstoves, however, don't allow for that. Since they are engineered with an eye toward better performance and reduced emissions, improved cookstoves generally have small, well ventilated combustion chambers, meaning they require regular attention. Participant observations suggested that the constant attention they require is part of the reason

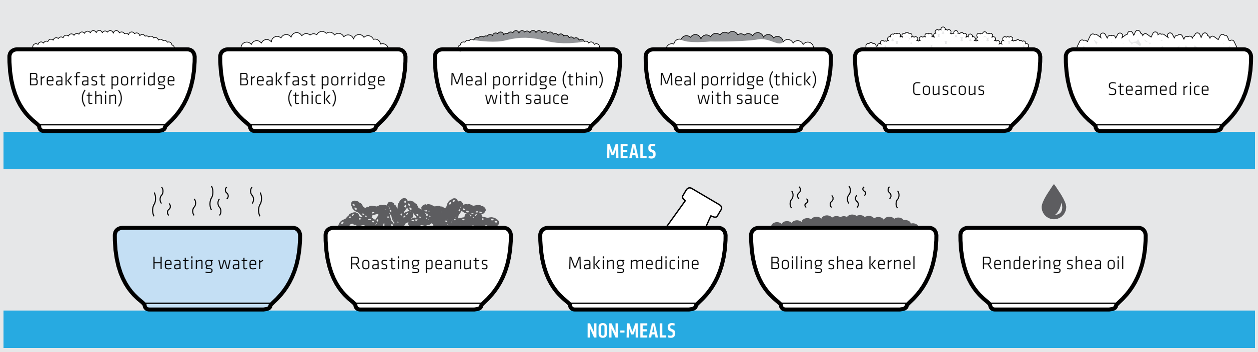


TABLE 3: Domestic cooking tasks

TABLE 4: Cookstove ownership for the village[10]

Number of cookstoves (% of total cooks)[b]	Number of cooks	Cookstove ownership[a]				
		TSF	GK	LTC	HCM	MM
1 cookstove (52.0%)	63	■				
	1		■			
2 cookstoves (35.8%)	29	■		■		
	6	■			■	
	5	■	■			
	3	■				■
	1		■	■		
3 cookstoves (8.1%)	5	■	■	■		
	3	■	■			■
	1	■		■	■	
	1	■		■		■
4 cookstoves (2.4%)	3	■	■	■	■	
5 cookstoves (1.6%)	2	■	■	■	■	■
TOTAL COOKS (% of total cooks)[c]	123 (100%)	121 (98.4%)	20 (16.3%)	42 (34.1%)	12 (9.8%)	9 (7.3%)

[a]Three-stone fire (TSF), gakourouwana (GK), low thermal capacity (LTC), hand-crafted metal (HCM), manufactured metal (MM). [b]Percentages do not add to 100% due to rounding. [c]Percentages do not add to 100% because some women own multiple cookstoves.

these ostensibly improved stoves were used infrequently in the village.

Other notable "day in the life" observations included the time and effort expended to collect wood—up to two hours per day, with bundles weighing from 14 to 22 kilograms carried distances of up to 4 kilometers—and the varied methods, from lighting straw or plastic to borrowing burning coals used to start fires. Women also preferred to prepare meals inside a kitchen and hot water outside the kitchen and they used multiple cookstoves for different types of meals and meal sizes (the three-stone fire is most commonly used). Perhaps the most notable observation, however, is that the culinary chain—gathering wood, preparing cooking ingredients, cooking meals, serving food, eating and cleaning—constitutes 65 percent of time that a married mother spends on daily chores and activities.

These findings and data suggest that cookstove adoption might increase if women believed, on balance, that the cookstove reduced their workload relative to existing practices.

STACKING STOVES

After participant observations suggested a high prevalence of stove stacking—the use of multiple cookstoves, each with a specific purpose—we looked to quantify the extent of stacking using data collected from surveys of cookstove ownership and use. These surveys were accompanied by in-depth interviews to understand owner decisions.

Cooking in the village spans six types of meals and five other non-meal cooking tasks see Table 3. The meals include two different types of breakfast porridges and lunches and dinners involved either a thick or thin porridge with a sauce or steamed rice or couscous, with variations on each. The tasks include chores such as heating water, roasting peanuts, or making medicine.

We found five types of cookstoves in the village. Most prevalent was the traditional three-stone open fire, with the cooking vessel balanced on stones over the burning wood. Another traditional type of stove is the gakourouwana, where the cooking vessel rests on a U-shaped support of mud or clay. There were also hand-crafted metal cookstoves made in Mali, and two types of improved stoves—a low-thermal-capacity stove made from clay and straw blocks and a manufactured metal cookstove that has been distributed worldwide. The two kinds of improved cookstoves had been given away by a non-governmental organization one to two years before our study, see Table 4.

Around half the women we surveyed engaged in stove stacking (they owned more than one stove). Nearly all own a traditional three-stone fire or a traditional gakourouwana cookstove, about 15 percent own both types of traditional cookstoves and 43.9 percent own a traditional cookstove as well as an improved cookstove. Interestingly, approximately 40 percent of women shared cookstoves. Due to the extended family structure in the village, there are often multiple cooks per household.

Often, women owned two or more three-stone fires so they could cook both indoors and outdoors. Meals were usually prepared in the enclosed kitchen, but during especially hot weather they were prepared outside. Hot water was generally prepared on an outdoor fire. Portable improved cookstoves were used more frequently than stationary cookstoves in the hot season because the stationary cookstoves could not be moved outside the kitchen.

Not a single woman owned only improved cookstoves—one of several strong indicators that improved cookstoves do not address all cooking needs in the village. No one who owned an improved cookstove used it frequently. Improved cookstoves were used to heat water and cook meals, but only traditional fires were used for activities such as roasting peanuts, making medicine and processing shea, see Table 5.

What's more, families with over 15 people, which accounted for approximately one-half of the village population, rarely used improved stoves because their large meals and large pots exceeded weight and size limitations of the improved stoves. The improved stoves were also too small or lacked the durability required

It's common for women within the same family to have separate kitchens and cookstoves.

to support large pots used for shea processing and to heat bathing water for large families.

SAVING FUEL

We also investigated the effects of cooking systems on fuel usage. We wanted to gather data on factors from the entire cooking environment rather than only the cookstove. We looked at 17 factors ranging from mass of the water and ingredients being heated and the size of the cooking vessel to the species and water content of the wood being burned.

Data on these factors were recorded in the 155 cooking tests completed across all meal types and stove types[8]. The tests were strictly observational. No wood or food ingredients were provided and no instructions given to respondents. This allowed respondents to cook as if it were a typical day.

Multiple regression analysis with forward selection was used to analyze the data. Six factors proved to be statistically significant in estimating energy use: the type of cookstove application, family size, total mass of wet and dry ingredients, mass of dry ingredients, the use of burning embers as an igniter, and the number of fires used during a cooking event. The smallest families, for example, used almost twice as much energy, per person, as families of 20 people.

It has been proposed that reducing grain flour size would reduce energy use in this village, the thinking being that smaller grains would cook faster. We didn't find any evidence to support that. The diameters of the various grains used in breakfast porridges, for example, differ by about a factor of two. However, there was no statistical difference in the energy used to cook them. While smaller particles cook faster, families cook each meal to a thickness defined by cultural preferences.

Most interestingly, little evidence was found to suggest that improved cookstoves significantly influenced cooking energy use after accounting for other factors. Only one stove had a statistically significant effect on energy use.

Though the specific numbers in our findings may not apply directly to other settings, they may suggest a general lesson: The impacts of cookstove improvements can depend more on factors in local cooking systems than on improvements in thermal efficiency. The actual fuel savings demonstrated by improved cookstoves in this case study were far smaller than savings measured in laboratory tests.

Actual savings can be calculated using the rated fuelwood savings in the laboratory, the adoption rate for the cookstove, how often each cooking task is performed, and the rate the cookstove is used for each task. Fuelwood savings for a consumer group can be calculated using the following equation:

(rated fuelwood savings) × (cookstove adoption rate) × (rate of each cooking task) × (rate the cookstove is used for each cooking task) = actual fuelwood savings

Taking the data on cookstove use and a rated fuelwood savings of 50%, the actual fuelwood savings for the low-thermal-capacity cookstove for this group of consumers equates to

$$(50\%) \times (100\%) \times (1.13\% \times 50\%) \times (100\%) = 0.28\%$$

TECHNICAL DESIGN GUIDELINES FOR COOKING TECHNOLOGY IN THE STUDY AREA

- Wood and charcoal are the only viable fuels in the short term. Petroleum fuel expenditures for cooking would be 7 to 11 times greater than current domestic energy expenditures. Biogas can only supply a limited amount of domestic cooking needs. Solar cookers would require substantial changes in meal times, eating practices, and work schedules due to agrarian living.
- A single improved cooking device will likely be insufficient to address the wide range of cookstove applications.
- Cookstove portability is important. Women prefer to cook meals inside the kitchen and heat water outside the kitchen. Further, approximately 10% of the village travels to hamlets during the farming season and would be unable to transport stationary cookstoves installed into kitchens.
- Stationary cookstoves may be lost when the wattle-and-daub kitchens collapse from heavy rains in the monsoon season.
- A delivered cookstove cost of US$10 seems to prevent purchase for many families that have access to an improved locally-made stove but do not own the stove despite stated aspirations.
- A solar water heater could displace a portion of domestic wood use. The outgoing water temperature from the solar heater should provide water that can be mixed to create bathing water of 39 to 48°C.
- Women can be away from the fire for up to 15 minutes. A cookstove that can maintain a stable fire over this interval without being tended could lead to faster cooking and reductions in incomplete combustion by avoiding a smoldering fire.

TABLE 5: Cookstove use for cooking meals

Meal	Percentage of all meals prepared (%)[c]	Percentage of meals prepared on cookstove (%)[a,b]				
		TSF	GK	LTC	HCM	MM
Breakfast porridge (thin)	17.86	7.78	92.22	0.00	0.00	0.00
Breakfast porridge (thick)	15.48	8.97	91.03	0.00	0.00	0.00
Lunch or dinner porridge (thin) with sauce	37.11	7.34	92.66	0.00	0.00	0.00
Lunch or dinner porridge (thick) with sauce	21.54	9.04	90.96	0.00	0.00	0.00
Rice	1.59	50.00	50.00	0.00	0.00	0.00
Couscous	5.29	0.00	100.00	0.00	0.00	0.00
Porridge[d]	1.13	0.00	100.00	0.00	0.00	0.00
Sauce[d]		0.00	0.00	100.00	0.00	0.00

The low-thermal-capacity cookstove was only used to cook porridge and sauce, which constituted only 1.13 percent of meals in the village. That rate was reduced by an additional 50 percent because that improved cookstove was used only in the sauce component of the meals; the grain component was prepared on a traditional stove. Although not completed here, a similar procedure can be used to calculate the realized reduction in emissions.

ENGINEERING FOR IMPACT

We found that in practice, consumer behavior significantly reduces the theoretical impact of improved cookstoves. For this village, the effect that cookstoves can have on fuel use is further reduced when considering that improved cookstoves are rarely used for non-meal activities. With only 64.5 percent of fuel used for cooking meals, the total fuelwood reduction for all domestic cooking and heating activities is just 0.18 percent for the selected group of women.

> Not a single woman owned only improved cookstoves — one of several strong indicators that improved cookstoves do not address all cooking needs in the study village.

The adoption of other technologies, such as solar hot water heaters, may have comparable or greater impact on wood reduction and human health. For example, consider a group of families that use a solar water heater for 50 percent of their bathing water needs. For this group, heating water accounts for 27.4 percent of cookstove energy use, the solar water heater would reduce domestic wood usage by 13.7 percent.

We suggest that the engineering challenges posed by cookstoves be approached by in-depth studies of human, natural, and built system factors, and a comparison of how these factors affect technology impact. The investigation can improve the health and environmental impact of cookstove programs by offering guidance in stove design and implementation. Our findings suggest a variety of technical and programmatic guidelines for increasing the impact of cooking technology programs. While specific guidelines, like the 0.28 percent fuelwood savings, may be unique to this village rather than universal, the systemic approach they represent may apply broadly.

It also seems reasonable to expect that no single cookstove option will replace the three-stone fire in the village we studied. After all, consumers in the developed world also utilize different technologies for making soup, cooking vegetables, baking bread, making toast, grilling meat, and heating our bathing water. In noting this, we can take a lesson from our own kitchens when designing cookstoves for the developing world: We should consider designing multiple technologies to meet needs that are as varied as our own.

PROGRAMMATIC DESIGN GUIDELINES FOR COOKING TECHNOLOGY IN THE STUDY AREA

- Operation and maintenance costs (including fuel) of a new technology must be small relative to income to be a viable alternative to current energy use patterns and technologies.
- Rental of capital-intensive options is preferred over full purchase to reduce consumer risk.
- Warranties are another assurance that can be given to the user to promote technology adoption by reducing consumer risk.
- A cookstove delivery service was not viewed as an important offer if the cookstove is portable.
- Technology adoption is strongly influenced by reduced work relative to existing practices.

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FOOTNOTES

[1] World Bank 2011

[2] World Health Organization and United Nations Development Programme 2009

[3] Johnson and Bryden 2012a, Ruiz-Mercado et al. 2011, Miah et al. 2009

[4] Johnson and Bryden 2012a

[5] Johnson and Bryden 2012a, Johnson and Bryden 2012b

[6] Klugman 2010

[7] Klugman 2010

[8] Johnson and Bryden 2012b

[9] from Johnson and Bryden 2012a

[10] from Johnson and Bryden 2012b

[11] from Johnson and Bryden 2012b

[a] Three-stone fire (TSF), gakourouwana (GK), low thermal capacity (LTC), hand-crafted metal (HCM), manufactured metal (MM).

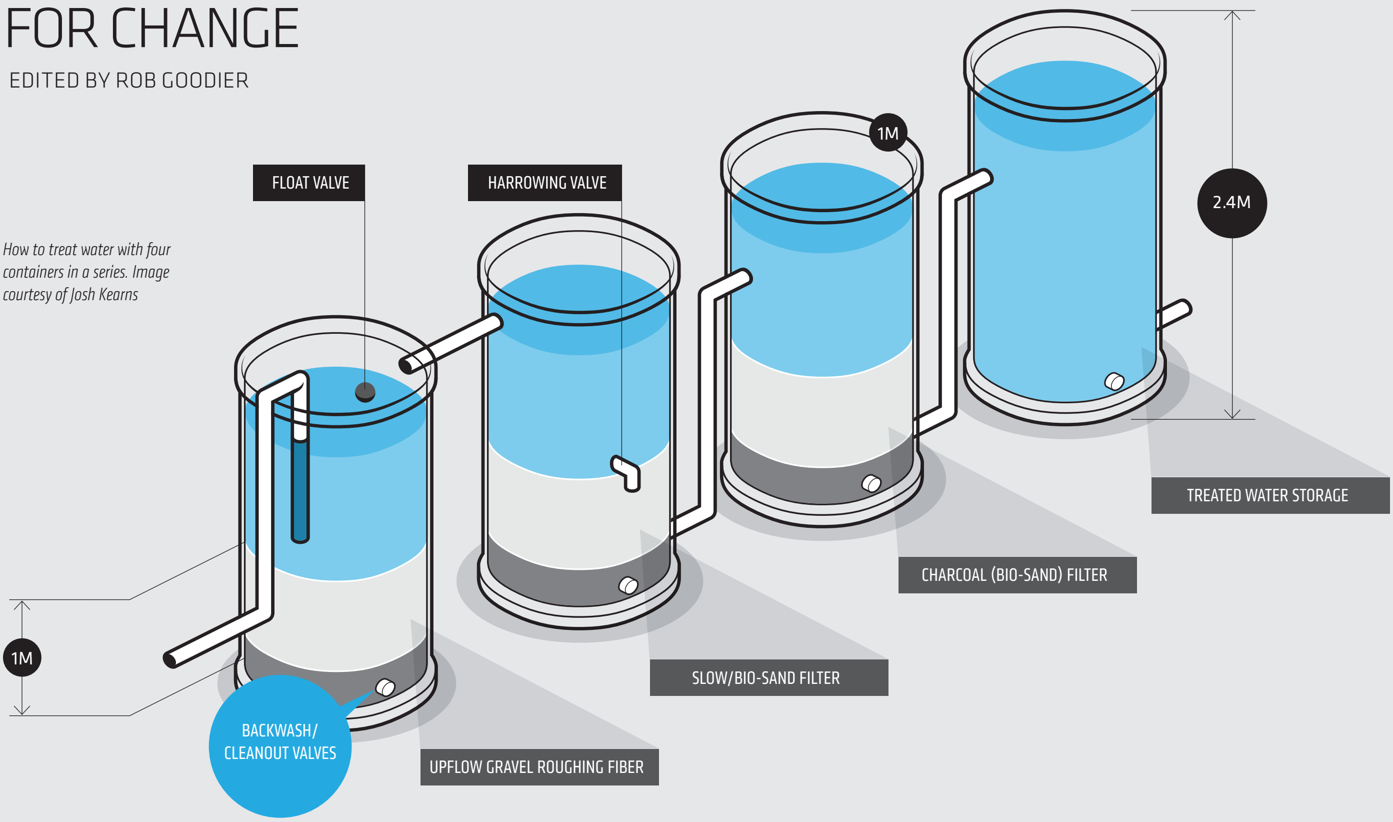
[b] Rows may not sum to 100% due to rounding.

[c] Column may not sum to 100% due to rounding.

[d] Indicates porridge and sauce meals that are prepared on two different types of cookstoves.

ENGINEERING FOR CHANGE

EDITED BY ROB GOODIER



How to treat water with four containers in a series. Image courtesy of Josh Kearns

An ancient filtration material removes pesticides from drinking water

CHARCOAL HAS BEEN A part of water treatment for at least 4000 years, but can it remove modern synthetic pesticides from drinking water? Farmers in northern in Thailand, concerned about agricultural runoff, put the question to Josh Kearns, an environmental engineering doctoral candidate at the University of Colorado in Boulder and the science director at Aqueous Solutions, a non-profit water, sanitation and hygiene development organization.

"I didn't know the answer, and searching the scientific literature revealed that, in fact, no one knows the answer," Kearns told E4C.

The answer, Kearns discovered through his own tests, is that it can. But a lot depends on how you make the char.

GASIFIERS AND CHAR

The Thai communities make their charcoal in traditional kilns that, when burning well, heat the material to 350 to 500 C. In contrast, simple gasifiers burn at 900 C. At that temperature, the wood and agricultural waste that they burn converts more completely into char. The biomass releases gases as it heats, opening up pockets in the material. The result is highly porous char that is suitable for water filtration.

DESIGN PRINCIPLES

One problem with introducing new technology is that people might not use it if it doesn't feel comfortable to them.

"Don't fight culture; if people cook by stirring their stews, they're not going to use a solar oven, no matter what you do to market it," says Ethan Zuckerman, founder of Global Voices. Zuckerman's advice and the maxim "consider context" is the second of E4C's Design Principles, found in our Learning Lab.

Gasifiers seem like a match. They operate in

> "One problem with introducing new technology is that people might not use it if it doesn't feel comfortable to them."

a way that is similar enough to kilns, and after a demonstration, they proved to be superior.

WATER TREATMENT WITH LOCAL MATERIALS

Working with the farmers, Kearnes built gasifiers and a char-based water treatment system.

It's hard to overstate the importance of using locally available materials, and the water treatment systems Kearns and the farmers are developing are entirely local. Kearns' system links four containers in a series, the first three filled with filtering materials such as sand, char and stone, and the final container holds the pure water.

Alex Odundo's sisal twine manufacturing machines

ONE BROAD, POINTED LEAF plucked from the sisal plant can earn a Kenyan farmer 5 shillings, or about $0.05 USD. But the same leaf, processed, spun into twine and spooled can sell for 100 shillings, or $1.15. That added value looked like opportunity to Alex Odundo, a Kenyan engineer and inventor who has developed three machines to turn sisal into twine.

As a child, Odundo would sit with his mother and strip off the husk of the sisal leaf by hand. That is how Kenyan farmers and their families usually process the leaf, if they process it at all. The slow work inspired the idea to automate the process. Fifteen years and many prototypes later, with a degree from Kisumu Polytechnic and a family of his own, Odundo has developed the machines and he sells them through his company Sifa Machinery.

Now, he would like to mass produce them and sell them more cheaply to farmers. Here's a snapshot of what could be the future of sisal twine production in rural Kenya.

SISAL DECORTICATOR

The decorticator is a cylindrical drum in a frame with blades that strip the green husk from the sisal leaf and grind the inner fiber into strands.

It has a five- to six-horsepower motor that can be either diesel or gasoline powered. The machines cost $500 to $700 to make, depending on the model, and Odundo sells them for $850 to $1,200. The prices should drop with mass production.

SISAL TWINE MACHINE

The twine machine spins the sisal fibers into a thin twine. It is composed of a 0.5-horsepower electric motor, a fly arm, bobbin, hub, friction belt and a smaller feeding motor of 1/16 horsepower. It is small enough for a farmer to use on the doorstep, Odundo says. It costs him about $350 to make by hand and he sells it for $600.

SPOOLING MACHINE

The sisal rope spooling machine packs the spun twine to prepare it for sale. It can spool different quantities and includes a two-horsepower motor that spins a couple of rollers. It costs Odundo about $1,000 to make and he sells it for $1,400.

THE BOTTOM LINE

With one decorticator and two twine machines, a farmer can grind and spin 120kg of sisal into twine in eight hours. That amount could sell for $120, Odundo says.

> "In the past, farmers were forced to sell the few sisal plants that they have along fences to business men who exploited them."

SISAL THE SAVIOR

Odundo has called sisal a savior to Kenya and it's not hard to see why. The sisal is an agave thought to be native to the dry Yucutan Peninsula of Mexico, and it thrives in semi-arid climates. More than half of Kenya is semi arid. So, a plant like sisal that does not wither during long droughts really could be a boon to farmers. But only if they can process it efficiently.

"Despite sisal being a potential cash crop, no one was willing to plant more because of the processing methods being used. These were labor intensive with poor-quality products," Odundo told E4C by email.

Now, small farm holders are planting more and making more money using this new sisal twine manufacturing equipment, Odundo says.

THE FUTURE OF SISAL TWINE

Odundo has become something of a media sensation since he presented his decorticator at Maker Faire Africa in 2010. Since then, he became a TED Fellow in 2012. Moving forward, he has plans to improve the machines.

THE BOTTOM LINE

WITH ONE DECORTICATOR AND TWO TWINE MACHINES, A FARMER CAN TRANSFORM:

120kg

OF SISAL INTO TWINE IN **EIGHT HOURS**

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Five questions with Sasha Kramer

SASHA KRAMER'S ENTHUSIASM FOR RECYCLING POOP IS CONTAGIOUS. After hearing from her, it's not hard to imagine the need to give your indoor bathroom a Stone-Age renovation. She developed EcoSan latrines that store human waste in removable 15-gallon drums for composting. Toilets that transform waste into compost are the key to healthy soils and sustainable living, Kramer says. In that case, maybe everyone's toilet should be a modified pit latrine?

Another key to sustainability is sanitation itself. Kramer promotes both, taking her message of back-end recycling (get it?) to camps and communities in Haiti that have no waste treatment systems in place at all. To carry out the work, Kramer co-founded the non-profit organization SOIL, Sustainable Organic Integrated Livelihoods. SOIL and its partners build and manage latrines, compost centers and vegetable gardens and they hold sanitation workshops in Port au Prince.

Kramer's interests don't end at poop, of course. She holds a doctorate in Ecology from Stanford University, and she's an adjunct professor of International Studies and a Visiting Scholar at the Center for Latin American Studies at the University of Miami. She also co-founded SOL, Sosyete Oganize pou Lanati, a Haitian non-profit advocate for environmental justice and ecologically sound development. We asked her five questions.

E4C: What is one thing that a lot of us don't know, but should know about poop?

SK: Everyone knows that poop smells bad and can make you sick but what few people think about is that poop can also be an invaluable resource, both from both public health and environmental perspectives. An adult will excrete most of the nutrients that we eat back into the environment in our poop and pee. These nutrients are critical for plant growth and soil restoration. If treated properly, poop can be transformed from a pathogenic and smelly mess that causes illness and environmental degradation, into a rich fertile soil that can be used to grow more food.

E4C: What is one of the promising trends that you see in sanitation in Haiti and other developing countries?

SK: Haiti's government sanitation program is very young, with the sanitation directorate only being formally established in 2011, but already one of the four pillars of their national strategy is the valorization of human waste. It is encouraging to see this objective incorporated into a national sanitation strategy early in its development.

Many countries are beginning to move in this direction but it is late in the game. Changes to existing systems are so much more challenging then actually building sustainability criteria into the system from the get go. As Haiti's first wastewater treatment system was constructed just last year, there is basically a clean slate for future sanitation developments and the inclusion of recycling wastes into the countries sanitation infrastructure will have a huge impact on Haiti's soils.

E4C: In your work, what has been one of the most instructive mistakes that you've made, and what did you learn from it?

SK: One of my biggest mistakes came from being overly enthusiastic about poop. When SOIL first began working in Port au Prince we were so eager to demonstrate that poop can actually be a resource that we may have gone too far with our enthusiasm to the point where people were coming to the compost site to watch the dumping and hopping up on the edges of the compost bin to get a closer look. When the cholera epidemic broke out in Haiti in October 2010 we had to close down one of our compost sites because the community had become so comfortable with the process that people were no longer taking the appropriate precautions.

We are now much more cautious to present both the dangers and the potential benefits simultaneously so that people understand that in order to make human wastes safe they must first be transformed through a carefully controlled process. Poop is dangerous if not treated properly, but compost made from human wastes is an incredible resource. People have to be given credit for being able to understand the difference.

E4C: What do you think is a dead end in your field that some people just won't let die?

SK: One of the benefits of coming into a field from an outside discipline (I am an ecologist working in a field traditionally dominated by engineers) is being able to provide a new perspective on practices that are rarely questioned from within the discipline. I have always felt that sewage discharge into oceans is a shortsighted approach to a problem with long-term implications. For over 100 years engineers have been designing deep-water sewage outfalls for urban wastewater with the idea that the dilution effect of the ocean will essentially treat the sewage, eliminating the public health risk and reducing the costs of sewage treatment. While this practice may be relatively safe from a public health perspective, it can never be considered sustainable from an ecological perspective. Nutrients in human wastes come from the food we eat, and are ultimately extracted from agricultural soils. If those nutrients are taken from the soil and not returned, soil fertility will progressively decline increasing malnutrition and reducing farmer income around the world.

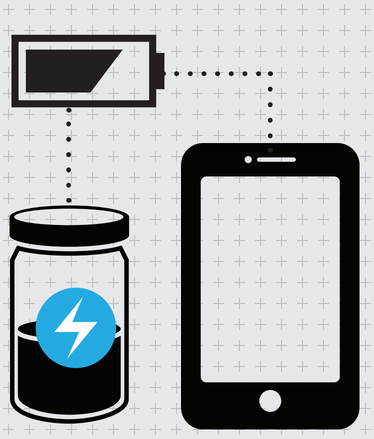
Modern science has responded to this dilemma through the production and application of synthetic fertilizers, derived through an energy-intensive nitrogen fixation process called Haber Bosch. Although this process has been wildly successful for increasing agricultural outputs, it is highly dependent on inexpensive fossil fuels. In addition, the industrial fixation of nitrogen and subsequent discharge of that nitrogen into aquatic ecosystems has significantly shifted the nutrient balance of global ecosystems and we are only just beginning to understand the long-term consequences of these changes.

The long-term sustainability of sanitation technologies is going to require a shift in thinking. Instead of dealing with the problem by shunting it to another ecosystem we need to consider transforming wastes into resources so that they can be recycled into the ecosystem from which they were extracted.

E4C: Five years from now, what improvements would you like to see in the technology that you and the people you work with use?

SK: I am hoping that rigorous research initiatives will be able to keep up with implementation in the field of ecological sanitation. There is tremendous potential for the reuse of human wastes to positively impact both human health and the environment, but there are also great risks involved when implementation programs are rushed without proper research and development.

My hope for the next five years is that sanitation professionals will work closely with academic institutions to ensure that new technologies are adequately researched before being brought to scale. This is an issue in Haiti currently as large NGO's are now taking an interest in ecological sanitation. Often, donor timelines require that projects be implemented on a large scale over a very short timeline and this can result in large-scale mistakes. Although SOIL is obviously supportive of ecological sanitation, we also work to encourage other organizations and government bodies to take the time to pilot new technologies in the communities where they are working before bringing them to scale to ensure that they are accepted by the community and safe for people and the environment.



IN THE LAB: Prototyping involved 3D-printed fuel cells powered by synthetic urine. When stacked in a series, the fuel cells generated enough power to charge a smart phone and enable text messaging, Web browsing and brief calls.

These cell phones are not technically urine powered

RECENT HEADLINES RAISED EYEBROWS AT E4C when Bristol Robotics Laboratory announced that it had charged a cell phone with urine power. Did anyone else imagine a sari-wrapped Indian small business owner holding up her dead Nokia and asking, "you want me to do what to this?"

But a closer looks shows that these phones are not exactly urine powered, and the concept they are based on may have potential. The new device is a microbial fuel cell. It's a urine-powered variant in which microorganisms feed on compounds in urine and generate electricity. When stacked in a series, the fuel cells have generated power to charge a smart phone just enough to send text messages, browse the Web and make a brief call.

As this technology advances, we could see bathrooms in the future that turn our waste into electricity and clean water. That could have advantages in both developed and developing countries.

"One product that we can be sure of an unending supply is our own urine. By harnessing this power as urine passes through a cascade of microbial fuel cells, we have managed to charge a Samsung mobile phone," Ioannis Ieropoulos from University of the West of England, Bristol, said in a statement.

"We are actually re-using waste to create energy," Ieropoulos says.

The researchers 3D-printed their fuel cell prototypes and fed them with synthetic urine in the lab.

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CASE STUDY

HELPING THE DISABLED GET OFF-ROAD AND ON WITH THEIR LIVES

The Leveraged Freedom Chair is a product of stakeholder-driven innovation—the designers teamed successfully with partners and customers to get it right.

03

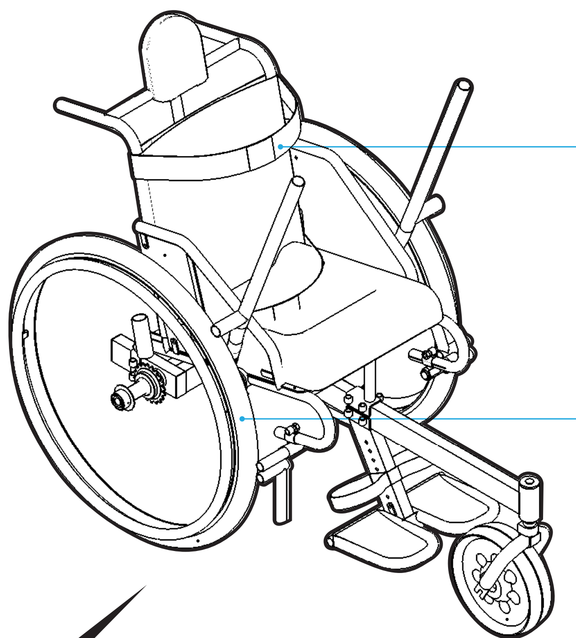
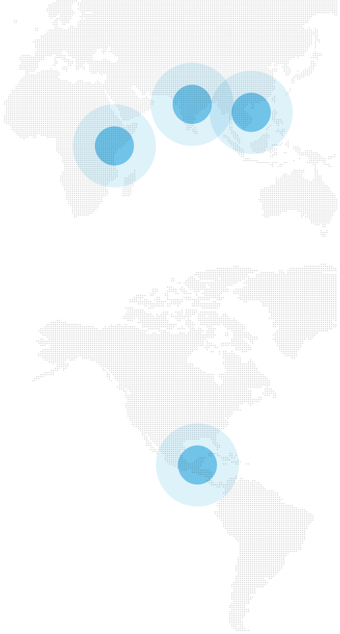


FIG 1: Indian Prototype LFC Assembly

AMOS WINTER is the Robert N. Noyce Career Development Assistant Professor in the Department of Mechanical Engineering at MIT. His work focuses on the marriage of mechanical design theory and user-centered product design for emerging markets and developing countries. He is the principal inventor of the Leveraged Freedom Chair. He is also a founder of Global Research Innovation and Technology.

EAST AFRICA, INDIA, VIETNAM & GUATEMALA



In the United States and other developed nations, much of the built environment is designed to accommodate people in wheelchairs. Most locations in urban areas are accessible via modest-grade ramps and smooth sidewalks possessing curb cuts. The goal is for people with mobility-based disabilities to have as much independent access to these locations as possible. ¶ The reality is much different for the 20 million to 40 million people in the developing world who require the use of a wheelchair [17, 6, 2]. Paved roads and sidewalks are often non-existent, and in many cases locations are linked only by a network of rough or muddy footpaths. In such conditions, a conventional wheelchair provides only limited mobility and the ability for people with disabilities to help support themselves is restricted.

STAKEHOLDER-DRIVEN INNOVATION

The idea behind the Leveraged Freedom Chair (LFC) was conceived – and the technology evolved – through field trials in East Africa, Vietnam, Guatemala, and India. The LFC project is an example of stakeholder-driven innovation. That is, our partners in developing countries did not simply articulate their needs, but they participated in the entire design process in order to identify and then create solutions as well.

The technology was directed towards a tractable and viable product by engaging stakeholders that represent each link in the

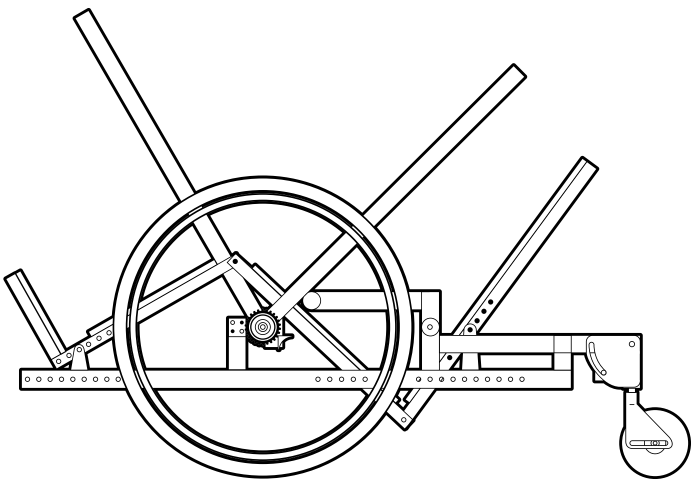


FIG 2: Kenya Prototype LFC [Side View]

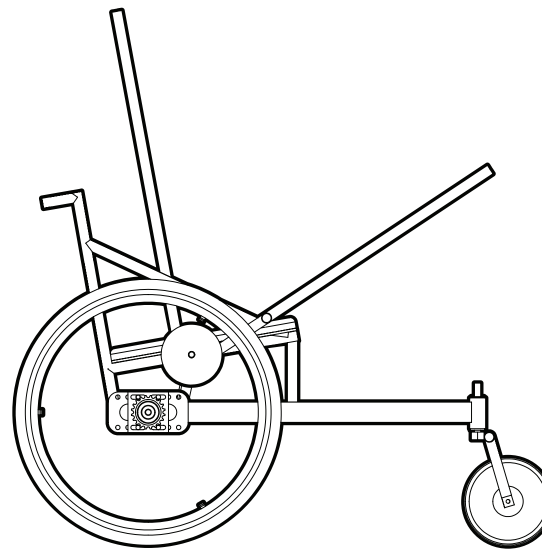


FIG 2A: East Africa Prototype LFC [Side View]

chain from inception of an idea to its implementation in the real world. These included end users of course, but also part suppliers, manufactures, and distributors of wheelchairs in developing countries. Stakeholders were integral in identifying design failures, such as our first prototype (see Figure 2), which was heavy, unstable and awkward to get into. They also deserve credit for many of the design elements that make the current LFC a viable product (see Figure 1), such as its low center of gravity and compact/maneuverable form.

When conceiving the project, we started with the notion of creating a product that could meet the mobility needs—both indoor and outdoor—of people with disabilities in the developing world. There is great demand for a device like the LFC because many people living in rural areas must traverse rough roads and muddy walking paths to find connections to community, employment and education.

The LFC fills an important niche in the developing world mobility aid market because many currently available products are limited in their capability. The most common mobility aids in the developing world are conventional, pushrim-propelled

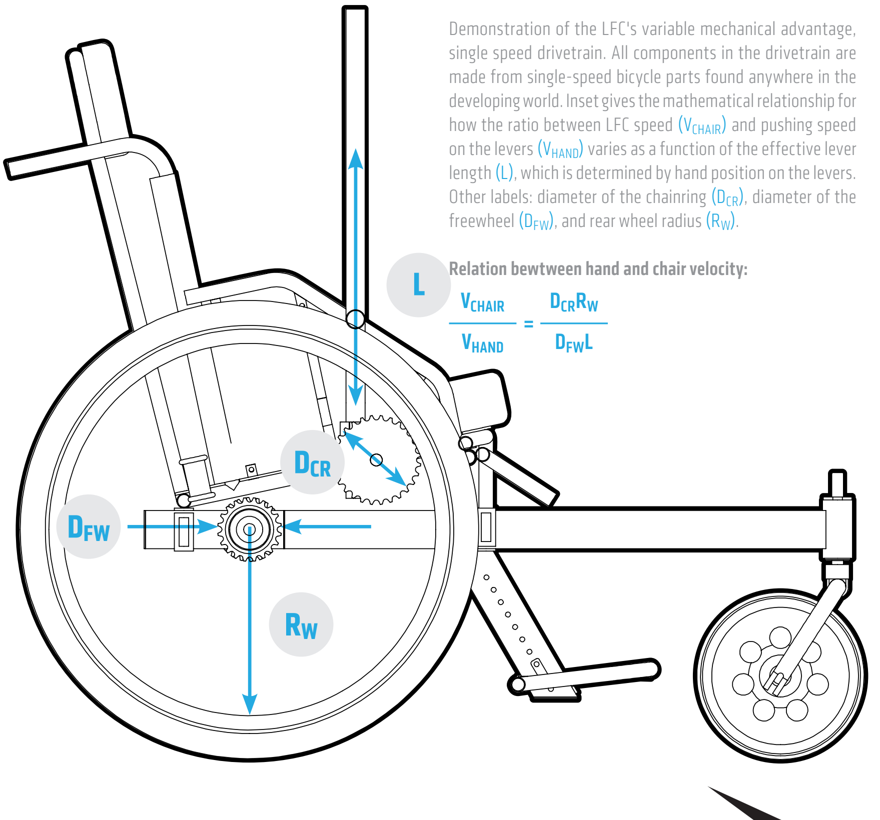
Partners in developing countries participated in the entire design process.

wheelchairs and hand-powered tricycles. Pushrim-propelled wheelchairs are inefficient to propel [20] and are exhausting to use for long distances on rough roads. Hand-powered tricycles, which are often preferred by users if they have adequate torso stability [11], are more efficient to propel than a wheelchair [20, 19, 18], but are difficult to maneuver on soft ground and up steep hills. They are also much too large to use inside the home.

The LFC combines the salient features of chairs currently on the market with multiple features modified or added as the result of field trials, such as a back pad to improve tipping stability, Velcro straps for extra security, and instructional lessons on how to use the chair that are included with purchase. We also made the LFC's seat and footrest adjustable and offer the chair in three different widths to accommodate varying user size and meet World Health Organization Standards. One important aspect of the design was the decision to make all of the LFC's moving parts from bicycle components, so that the chair can be repaired by local bicycle technicians commonly found in rural and urban areas of developing countries.

FORM AND FUNCTION

The LFC is a three-wheeled wheelchair that is propelled through a lever-powered drivetrain. Instead of using multiple gears to change speed, the LFC user varies mechanical advantage by sliding his or her hands up and down the levers. Pushing forward on the levers propels the chair through a single-speed assembly of bicycle components; pulling back ratchets the drivetrain and resets it for the next stroke. Pulling all the way back engages the brakes, which are the small bars that protrude from the levers and rub against the tires. Human power and force output capabilities were used to determine a lever size and drivetrain geometry that enables the user to efficiently travel on smooth surfaces and gentle grades, and produce enough torque to overcome harsh terrain [23].



Demonstration of the LFC's variable mechanical advantage, single speed drivetrain. All components in the drivetrain are made from single-speed bicycle parts found anywhere in the developing world. Inset gives the mathematical relationship for how the ratio between LFC speed (V_{CHAIR}) and pushing speed on the levers (V_{HAND}) varies as a function of the effective lever length (L), which is determined by hand position on the levers. Other labels: diameter of the chainring (D_{CR}), diameter of the freewheel (D_{FW}), and rear wheel radius (R_W).

Relation bewtween hand and chair velocity:

$$\frac{V_{CHAIR}}{V_{HAND}} = \frac{D_{CR}R_W}{D_{FW}L}$$

FIG 3: Detailed LFC diagram showing drivetrain technology

Varying mechanical advantage by changing the user's geometry (i.e., hand position on the levers), rather than the machine's geometry, allows the LFC drivetrain to be built from a lightweight, single-gear ratio chain drive made from bicycle components. These components provide a 3:1 change in mechanical advantage, cost less than $20 USD and are commonly found in the developing world [10]. To put this performance/cost ration into perspective, top-of-the-line Shimano XTR mountain bike components provide a 6:1 change in mechanical advantage, but cost more than $1,500 USD [14, 4].

The price of the LFC, when produced in India and sold in bulk, is $200 USD, while a single LFC is $250 USD. This price point is within the same range of the most commonly distributed wheelchairs in developing countries [22, 5, 21, 8] and is 25 to 30 times less expensive than off-road wheelchairs with similar capabilities offered in the developed world [12, 9, 15].

The LFC weighs 21.4 kg (47 lbs), which is within 2.3 kg (5 lbs) of other manual wheelchairs available in the developing world. Achieving this weight was a challenge, as the drivetrain alone (which includes the levers, chainrings/couplings, freewheels, chains, axles and bearings) weighs 5 kg (11 lbs). The weight was reduced through judicious use of steel in the frame by optimizing strength to weight of the members, making the seat subframe a fully triangular-trussed structure, and using lightweight clamps to connect the seat to the lower subframe.

The lever pivots are built directly into the seat pan to support the greater than 204 kg (450 lbs) peak chain tension, the highest loads commonly experienced by the chair. The LFC frame was designed to support over 600 kg (1,300 lbs) in the seat, corresponding to a 6X factor of safety compared to static loading. This safety factor was chosen by taking into consideration the fact that the front tube would principally fail in bending; that failure could result in injury to the rider; and that 6X static loading on the front wheel is conservative, as impacts, such as drops off curbs, are absorbed primarily by the rear wheels [13].

The LFC was built on a three-wheeled platform to enhance its mobility on rough terrain. This layout was inspired by a three-wheel model developed by the international disability charity Motivation. The long wheelbase reduces load on the front wheel, which combined with its large diameter enables it to roll over obstacles more easily than smaller casters placed closer to the rear wheels—such a layout is found on conventional four-wheeled wheelchairs. The LFC's three-wheeled layout makes it kinematically constrained with the ground. That means that no matter how rugged the terrain may be the three wheels provide three points of contact. On rough ground, four-wheeled chairs can be less stable than those with three wheels as one of the wheels can lift off the ground, similar to a tippy table with one short leg.

For indoor use, the levers on the LFC can be removed and stowed in the frame, which converts the chair to a regular, pushrim-propelled wheelchair.

DRIVEN BY FEEDBACK

The first field trial of a prototype LFC was conducted during the summer of 2008 with the chair in Figure 2. These LFCs were made and tested with the Association for the Physically Disabled of Kenya (APDK) in Nairobi; Mobility Care in Arusha, Tanzania; and Kien Tuong in Ho Chi Minh City, Vietnam.

The tests were informal. They lasted only a few minutes and were performed by technicians on the terrain surrounding the wheelchair workshops where the prototypes were built. The intent behind this design was that the user could climb over obstacles with the large front wheels and maintain a stable position with a low center of gravity. Our thought was that future iterations would have a swiveling seat and to put the big wheels in back for indoor use, similar to a conventional wheelchair.

We knew going in that the prototype would need some improvements. The consensus from the testing showed that the prototype would not work—it was awkward to transfer into and was much too heavy to be viable in the field. The chair would become unstable when going downhill, plus because the rear wheel would tend to swing around to the front. On side slopes, the uphill drive wheel tended to lose traction. This prototype was a failure, but it did provided a valuable lesson to the design team. We learned that by engaging stakeholders we were able to discover flaws early and were able to iterate to improve the design.

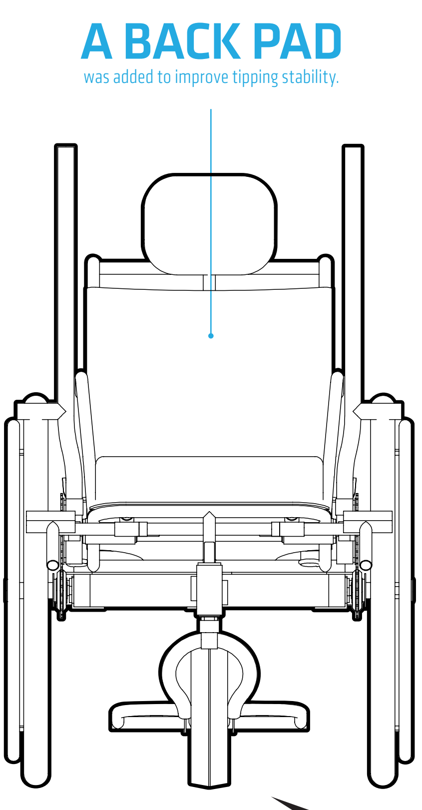


FIG 3a: Guatemala Prototype LFC [Front View]

A back pad was added behind the user's shoulders to improve tipping stability.

Together with partners in East Africa, our team designed the next iteration of the LFC, see Figure 2a. Six of these prototypes were produced with the Association for the Physically Disabled of Kenya (APDK). One chair was tested in Tanzania, one in Uganda, and the remaining four in Kenya. The trial ran from August 2009 to January 2010.

Although the chair received positive reviews on rough terrain, the six subjects felt the LFC was too wide to be used indoors [23]. This feedback made our team realize that the chair had to be a viable conventional wheelchair when the levers are removed, as the levers would typically be used only for an hour or two per day during long distance travel. The second concern, which was raised by five of the East African test subjects, was that the LFC tipped backwards too easily and felt precarious when going up hills. The final problem was that the LFC was too heavy. At 30kg (65 lbs), it was at least 9.1 kg (20 lbs) heavier than other developing world wheelchairs on the market.

CHANGES WERE MADE

The Guatemala LFC was designed in collaboration with our East African partners and the Transitions Foundation of Guatemala. Changes were implemented to rectify the issues raised in the East African trial, see Figure 3. The width of the chair was reduced by 8.9 cm (3.5 in), making it 68.6 cm (27 in) wide, which is approximately 1.3 cm (0.5 in) narrower than a hospital chair of the same seat size. This was accomplished by tapering the seat, putting jogs in the levers and using narrower tires than were used on the East African LFC. Backwards tipping stability was improved by lowering the center of gravity by 12.7 cm (5 in). A back pad (seen in Figure 3a behind the user's shoulder blades) was also added to improve tipping stability. This pad acts like a bench-press bench, providing a reaction force against the user's spinal column when he or she pushes on the levers, and thus preventing the user's torso from bending backwards over the seat. The mass of the Guatemala LFC was 20.4 kg (45 lbs), 9.1 kg (20 lbs) lower than that of the East African chair.

Twelve Guatemala LFC prototypes built by Transitions were tested around Antigua, Guatemala, from November 2010 to January 2011. The test subjects rated the chair's indoor performance nearly as highly as conventional wheelchairs. On an average daily commute on a rough village road the LFC averaged 1.14 m/s (2.55 mph), 81 percent faster than a conventional wheelchair [25]. Qualitative feedback about the LFC's comparable performance was not as compelling, presumably due to shortcomings in the design. Many subjects in the trial, particularly those who had sustained spinal cord injuries, wanted to be secured to the chair with straps to prevent from being pulled out of the seat when pulling back on the levers to apply the brakes while rolling downhill. Three of the 12 subjects requested that straps be standard in future versions of the chair. Five subjects suggested that the parking brakes be moved to a new position because the levers could hit them when propelling vigorously. The most common suggestion from the Guatemala trial, which was voiced by six subjects, was that recipients should be trained on how to use it.

THE FINAL TRIAL

The LFC was brought to India for its final trial, which was run in collaboration with Bhagwan Mahaveer Viklang Sahayata Samiti (BMVSS, commonly known as Jaipur Foot) [3], the largest disability organization in the world in terms of assistive devices provision. BMVSS was chosen as a partner because of its ability to scale up distribution of the LFC as well as its reputation as a leader in assistive device provision in the developing world. BMVSS facilitated a relationship with a production partner, Pinnacle Industries, an original equipment manufacturer of truck and bus seats—products similar in construction to a wheelchair.

The India LFC design, see Figure 1, addresses the critical feedback expressed by subjects in the Guatemala trial. Chest, waist and foot straps made of Velcro were added as standard features to the chair. The parking brakes were lowered by 12.7 cm (5 in) to allow for a larger stroke while still preventing the levers from hitting the ground in the event they were dropped by the user. Additionally, a training program was implemented on how to use the LFC. Each subject received more than two hours of instruction, including skills to cope with obstacles, before he or she took the chair home. The World Health Organization's "Guidelines for the Provision of Manual Wheelchairs in Less-Resourced Settings" includes training as a critical part of appropriate wheelchair provision [2].

Twenty-four India LFC prototypes were tested throughout the country from May to October 2011. Data from these tests showed that the LFC performed nearly as well as conventional wheelchairs indoors, and provided drastic advantages on rough terrains [25]. Eleven of the trial subjects were full-time wheelchair users, and 10 of them switched to the LFC as their primary mobility aid. These people traveled an average of 2.7 km per day and were able to average 0.91 m/s (2.04 mph) using an LFC during a common daily commute on their home terrain. This was 50 percent faster than what they could

FIG 4: Stakeholder Integration

> The India LFC design addressed the critical feedback from the Guatemala trial.

using the LFC. Conversely, using a conventional wheelchair, none were able to leave their home without the assistance of a family member. Four of these people were able to gain employment because of their newfound mobility.

Seven of the full-time wheelchair users in the trial underwent biomechanical testing achieve with a conventional wheelchair. The most common feedback following the India trial, voiced by seven of the subjects, was that the LFC should have cargo space. A storage bag that hangs behind the seat has since been incorporated into the product.

THE POWER OF THE CUSTOMER

Stakeholder input drove the evolution of the LFC, and with each design iteration performance was improved. Furthermore, the number and complexity of requested design revisions decreased with every trial. The relatively minor requests for upgrades following the India trial indicated that the LFC design was sound and perhaps even ready for commercialization.

The importance of the active participation of all the stakeholders cannot be overemphasized in the development of the LFC. The stakeholders represent each link in the chain from inception of an idea to its implementation in the real world. Figure 4 is a conceptual illustration of the importance of stakeholder involvement. The inner circle of the diagram shows the stages through which a technology matures; the outer circle represents the stakeholders best positioned to advance the technology through each stage.

The LFC successfully came to market because the outer stakeholder circle was fully represented in the project; each group had the opportunity to express requirements, constraints, and insight for driving the technology towards implementation in the real world. This design process, including identifying customer and stakeholder needs, is similar to commonly accepted product design practices [16], as well as methods aimed specifically at creating developing world technologies [7], with a few notable exceptions.

> The most important lesson is that development starts and ends with the people who rely on the product.

Representatives from the various stakeholder groups in the outer ring of Figure 4 were engaged concurrently during the development of the LFC. This approach enabled our team to understand the most important constraints and requirements associated with an improved rural area mobility aid. End users expressed a desire to travel long distances on rough terrain and navigate tight, indoor confines. Manufacturers such as Pinnacle, as well as APDK and Transitions, added design elements to improve production and identified that custom parts are difficult to repair or replace in the field—which we solved with the use of bicycle components. Wheelchair distributors, represented by APDK, Transitions, and BMVSS, set the price point of approximately $200, which makes the LFC competitively priced and the same cost to donors as other wheelchairs on the market. If these requirements were revealed in a linear fashion, as the technology moved from prototype to product, many more iterations may have been required to achieve the necessary performance, manufacture, repairability and cost specifications for the LFC.

Also unique in Figure 4 are the positions of academics and technology transfer firms. With the support of the Massachusetts Institute of Technology, the Singapore University of Technology and Design, and the Indian Institute of Technology Delhi, our team had the resources to innovate, test and iterate quickly. But the outputs of academic projects are typically proof-of-concept prototypes, not products ready for commercialization.

To bridge the gap between academia and industry, it was necessary to form a start-up, Global Research Innovation and Technology (GRIT), and engage the help of the Boston-based product development firm Continuum. These stakeholders were able to perform functions critical to bringing a product to market, such as design for manufacturing, quality control, and packaging. Our team also received frequent and valuable mentorship from Whirlwind Wheelchair International, an organization that has been designing and distributing developing-world wheelchairs for more than 30 years.

The LFC shows that the development and implementation cycle starts and ends with end users—the people best positioned to articulate a need and validate a solution. Navigating differences in culture, demographics and geography can be tricky, but it is critical for those of us creating technologies for developing countries and emerging markets to utilize stakeholder-driven innovation. We need to recognize end users—as well as all the other stakeholders of a technology—as part of our team in order to create a product that truly works on the ground. ⊗

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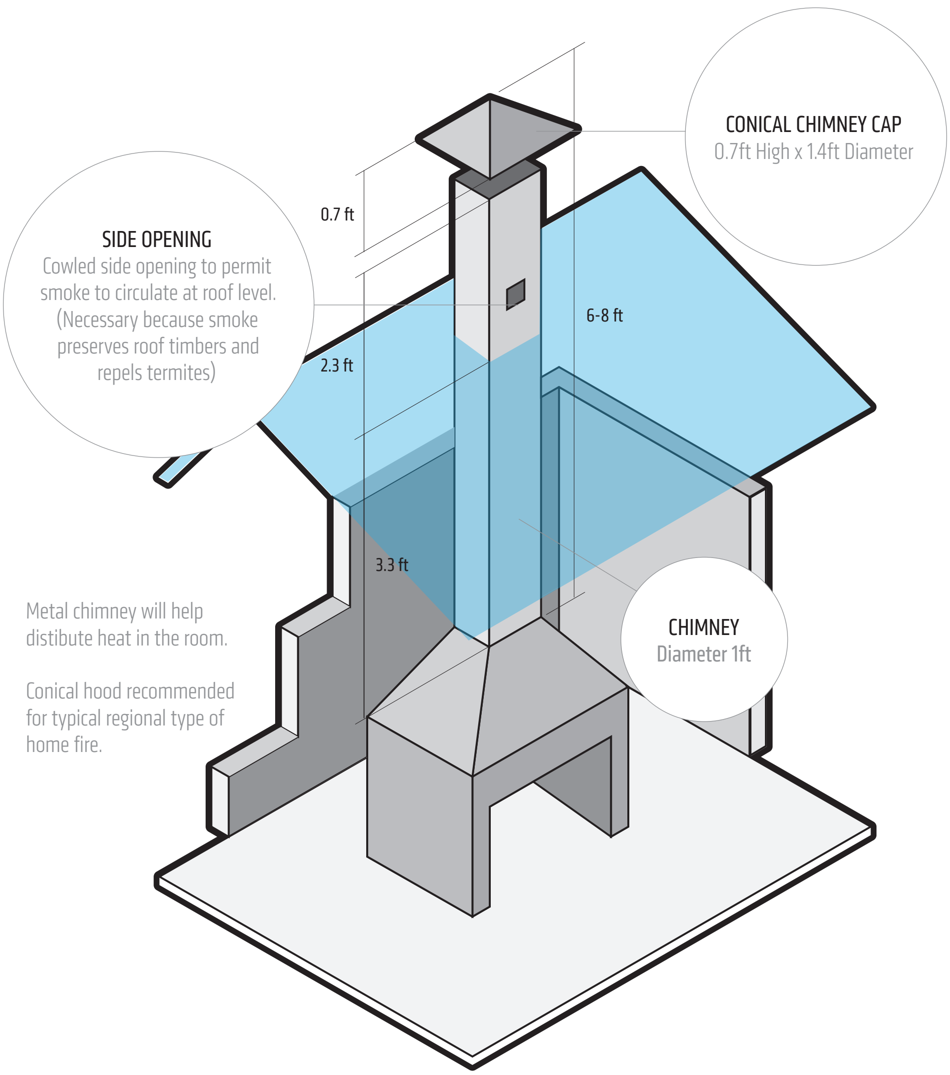
A BETTER WAY OUT

Smoke hoods are a solution to pervasive indoor air pollution. But not every design works under every condition.



Around half the people in the world and as many as 90 percent of rural households in developing countries cook using solid fuels or biomass, everything from coal to wood, dung and agricultural wastes. When such fuels are burned in rudimentary stoves, as is often the case, poor combustion results in high levels of indoor air pollution (IAP). Particularly damaging are particulates, which get into the lungs and may cause respiratory disease, and carbon monoxide. In poorly ventilated dwellings, IAP can be 100 times higher than acceptable levels, which the World Health Organization has designated as 50 µg/m3 small particles and 10 ppm carbon monoxide, both measured over a 24-hour period.

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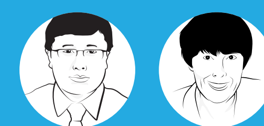

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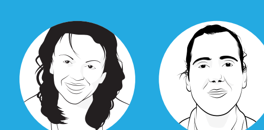

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GORKHZ REGION, NEPAL

ROADBLOCKS TO IAP AWARENESS

Despite being a global health crisis, there are a multitude of reasons why the issue of IAP has not received more attention internationally:

- Those most directly affected are very poor, often women and children with low status.
- Often biomass can be obtained at no monetary cost, and time cost is often not considered.
- Until recently, policy makers have not recognized the scale of the problem.
- Experts have failed to grasp that fuel-efficient stoves do not always alleviate smoke.
- The development community has focused on rural electrification, even though non-grid systems seldom produce enough power for cooking and people who are very poor cannot afford it for anything more than basic lighting.

In poorly ventilated dwellings, indoor air polution can 100 times higher than acceptable levels.

Pollution from cooking fires has been implicated in the deaths of nearly 2 million people a year, mostly due to diseases such as pneumonia, chronic obstructive pulmonary disease and lung cancer, and the toll is especially heavy on women and children.

Although a number of technologies that improve cooking performance exist, they often present a dilemma for agencies hoping to use cookstoves as a means to improve health and welfare. Efficient stoves, it turns out, are often dirty, clean stoves are often inefficient and the small number of technologies that perform well across both measures tend to be expensive, require advanced manufacturing techniques and are often non-intuitive to use. The potential availability, affordability and accessibility of any such technology remain necessarily limited.

One technology that can be used to effectively reduce levels of IAP is the smoke hood, which is often constructed from sheet metal and draws smoke upwards and through the roof, drastically reducing the levels of indoor smoke. Smoke hoods can be placed over open fires or improved cooking stoves and can be adapted to suit the country and local community requirements.

Following pilot projects conducted in Kenya, Tanzania and Nepal in 2009, the international development and technology charity Practical Action embarked on the Healthy Hoods project in collaboration with the global Bosch and Siemens Home Appliances Group (BSH) and the Bundeswehr University Munich. This project included the development of an online tool enabling users to input a variety of factors to produce a diagram and dimensions of an optimal smoke hood for their particular situation.

The project aimed to design and optimize smoke hoods for developing countries and establishing construction guidelines, specifically to:

- Increase awareness of the adverse health impact of IAP and create a demand for the smoke hoods.
- Demonstrate a sustainable mechanism of market promotion for this technology.
- Disseminate project learning and knowledge to a wider audience.

This case study examines the experience of implementing the Healthy Hoods program in the Gorkha region of central Nepal. The lessons Practical Action and its partners learned from this experience will enable the program to more widely disseminate smoke hoods in other locations.

FIRE AND SMOKE

The Gorkha region is an area that needs the means to improve its indoor air quality. The region is in the highlands of central Nepal at an elevation of 1,135 meters above sea level, and it has a population of around 300,000 residents. Due to cold temperatures in the region, indoor fires are used not only for cooking but also the heating of indoor spaces. The use of solid fuels and traditionally inefficient cooking stoves in poorly ventilated houses has resulted in IAP that far exceeds maximum levels as recommended by the WHO. This in turn has resulted in increased respiratory problems for residents, especially for women and small children.

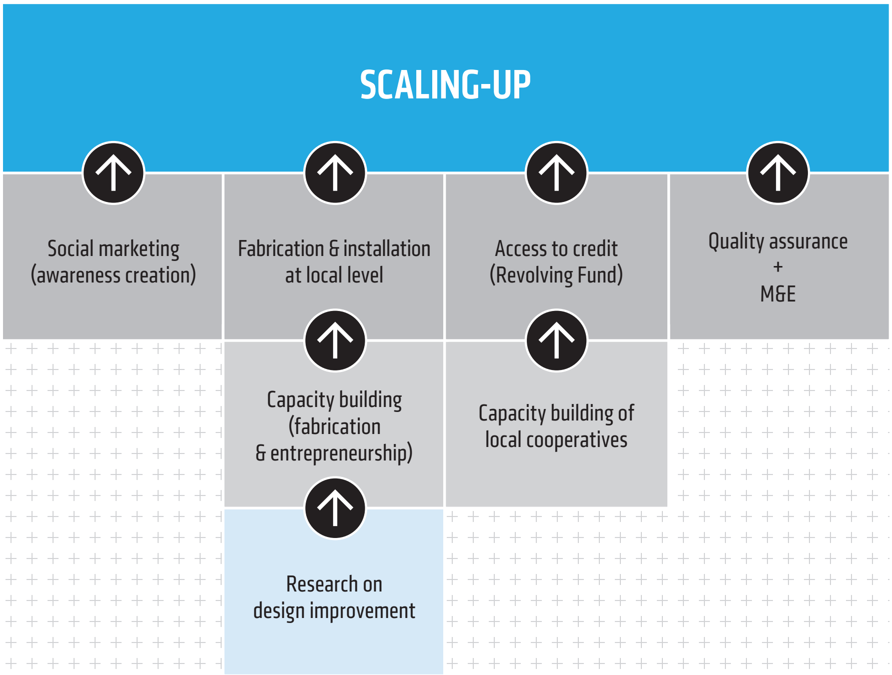
In 2011, Practical Action UK and Practical Action Nepal collaborated with Sam Shiroff, BSH's Senior Sustainability Specialist, and Dr. Liz Bates, an international household energy specialist, and researchers at Bundeswehr University for the Healthy Hoods project. This public-private partnership combined Bundeswehr University's thermodynamic expertise, BSH's marketing experience and corporate social responsibility goals, and Practical Action's technical expertise, for a holistic approach to the problem of IAP.

The main objective of Healthy Hoods was to design a smoke hood that would remove significant amounts of IAP, while offering a model that would not interfere with families' traditional practices and allow for them to place efficient—though not necessarily clean—cookstoves beneath it. The idea was that by using some of the most advanced computerized fluid design techniques it might be possible to dramatically improve the performance of the hood while keeping manufacturing costs low. Moreover, the smoke hood was designed to be simple enough to be manufactured locally and offer adaptations to accommodate local needs and habits.

Prior to this project, Practical Action had already completed field research with an initial smoke hood design. Practical Action learned that such hoods must remove adequate amounts of smoke while allowing for space-heating and for the smoke to be used for curing crops, smoking meat and coating wooden rafters with a layer of carbon to preserve the wood. The initial project achieved some notable benefits, with approximately a 60 percent reduction in smoke and a reasonable acceptance of the technology—by the end of this field test, about 1,600 families from three districts were using the smoke hoods.

The Healthy Hoods project was carried out over a two-year period, beginning in January 2011, see Figure 1. It was divided into two phases. The first six months were allocated for testing the technology and carrying out an acceptance study and design modifications, while the remaining time was allocated to scaling-up the optimized smoke hoods. The second scaling-up phase of the project was based on social marketing, fabrication and installation, access to credit and quality assurance.

FIG 1: Key components of the scaling-up phase



One of the major goals of Healthy Hoods was to establish sustainable financing so that the project was not dependent on subsidies.

TESTING THE TECHNOLOGY

The Department of Thermodynamics at Bundeswehr University designed the optimized Healthy Hoods. Researchers there used fluid dynamics software to model the flow of hot gases through the hoods. Gases in a pipe tend to flow smoothly until they reach points where either the direction or the cross-section of the pipe change. At such points, vortices and eddies can form, and the simulation model mimicked the issues that had been observed in the Nepali households during field tests.

For instance, the model found that if the front opening of the smoke hood is too large relative to the cross-sectional area of the flue, then gases can escape under the lip of the hood. The model also showed that vortices can form along the bottom corners of the hood, allowing smoke to escape at such places. Smoke hoods that had already been installed had exhibited this, with smoke marking the top edges and bottom corners of the smoke hood, and households complaining of smoke "blowback" on windy days.

Small changes in various key measurements were made to address these issues. Using mathematical modeling, the researchers in Munich optimized the ratio of the size of the opening to that of flue and created a lip along the vertical edges of the front opening to eliminate the vortex and to add stability to the hood. Fitting a cowl to the top of the flue reduced many of the issues associated with blowback on windy days. (Although an H-shaped cowl is more efficient many households preferred a smaller cowl which is not as efficient but removes sufficient smoke.) Finally, leakage between the smoke hood flue and the roof was resolved using a "skirt" of steel from the roof down to the joint.

Over the course of the design optimization, smoke reduction increased around 65 percent. However, science aside, it was critical to engage the local community in the design of the hood. Only the end users can know which issues are most important to the community, and which smoke hood design would best meet their needs and achieve the greatest acceptance.

Researchers developed and proposed different designs of smoke hoods, each varying across parameters such as size, shape of stake (either rectangular or round), and shape of cowl (single cap, double cap or H-shape). Mixing and matching these variables resulted in 32 different improved smoke hoods that were fabricated locally and installed in eight village development committees (or VDCs). This was a relatively small study due to high transport costs.

The project identified 50 potential local manufacturers and provided them a seven-day intensive training in the production of smoke hoods. That was followed by on-the-job mentorship to include skills in entrepreneurship and business management.

The trained manufacturers work in teams of three to five people. Since the fabrication of a smoke hood is relatively easy, the workplace can be set up wherever it is required, and most have been set up close to the user communities. The local cooperatives support the manufacturers by providing temporary space for the workshops.

It takes one full day for a skilled three-person team to manufacture and install a smoke hood. The team receives around NPR 1,500 (US $17) per hood, which provides an income of NPR 500 (US $6) per person per day, a good income in rural Nepal. To diversify their businesses, the manufacturers also produce a variety of household items, including grain storage bins and trunks.

A local quality control group, including representatives of the local cooperative, users and the local government, was formed in each village to check on the end product. Warrantee cards were issued by the manufacturers with a free one-year maintenance service guarantee. Quality indicators of the product were developed and efforts were made to standardize smoke hood design based on local needs. Periodic monitoring of product quality and after sales services were conducted by trained staff.

After installation of the smoke hoods for testing purposes, an acceptance study was carried out through a team of consultants. Based on the recommendations generated from that study, further modifications were made to the design.

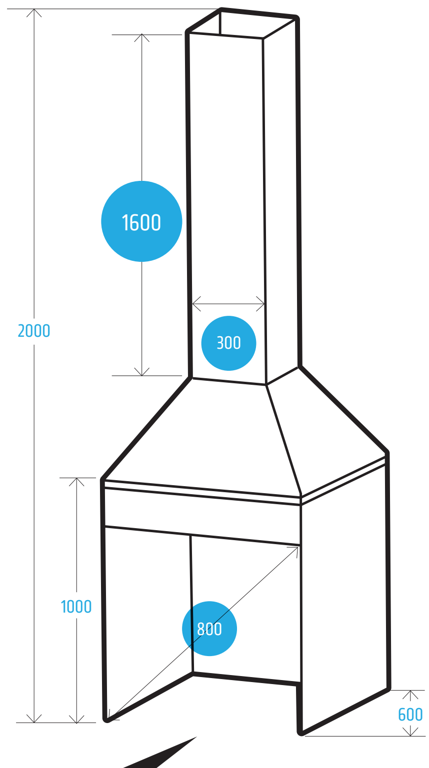


FIG 2: Smoke hood design

CREATING DEMAND

Following the initial technology testing and acceptance study, the Healthy Hoods project used a demand-based approach to create a market for the optimized smoke hoods technology, see Figure 2. Due to a low awareness of the problem of IAP in the local communities, that approach required extensive time and effort.

The project launched awareness campaigns to train approximately 25,000 people on the danger posed by IAP and used FM radio broadcasts and monthly meetings of cooperative members to disseminate IAP-related information. It taught techniques for drying wood fuel, reducing personal exposure to smoke and the time spent for cooking, using pot lids for cooking efficiency and adopting better hygiene. The project disseminated educational materials on health and the economic impacts of indoor smoke to 5,017 households and trained 96 Female Community Health Volunteers, 50 teachers, and 1,350 students on the adverse health impacts of IAP. All of this was done with the close cooperation of local health service centers.

Monthly meetings were the most effective approach in creating demand for smoke hoods. Another successful approach was identifying community leaders as early adopters and convincing them to install smoke hoods at their respective homes. This provided an opportunity for the community to observe the benefits of the new technology and that in turn triggered an increased demand in the project areas.

Creating awareness of the problem wasn't the only means to build demand. A Healthy Hood costs about NPR 6,000 (US $72)—a large sum for a poor family to pay upfront. One of the major goals of Healthy Hoods was to establish sustainable financing so that the project was not dependent on subsidies. A revolving fund mechanism was organized by nine local cooperatives in order to provide loans to households for smoke hood installation. A deposit of NPR 1,000 (US $12) per household was required to order a smoke hood, with the remaining NPR 5,000 (US $60) granted as loan from the cooperative. The terms and conditions of the loan are very similar to a standard loan system, with the exception of the interest rate, which is 5 percent or less, compared to a standard rate of 18 percent.

About 5,000 households have been granted loans totaling NPR 4,003,200 (US $46,185), and repayment rates are regular and as per the guidelines provided by the project. At the end of January 2013, approximately NPR 588,800 (USD 6,795)—14.71% of total disbursed loan—of loans repayments had been collected and the cooperatives were successfully using the revolving fund for the scaling-up of smoke hoods and other income generating activities.

A total demand of 834 smoke hoods was received during the two-year project period, not including the 32 hoods installed for testing purposes, see Figure 3. At the start of the project, installation of smoke hoods was slow, though this increased dramatically at the midway stage, but decreased towards the end of the project. However, the local cooperatives continue to receive further loan requests for the installation of additional smoke hoods, with the number expected to increase in the future.

INDOOR AIR POLLUTION MONITORING

To gauge the success of the smoke hoods, the project needed to measure the improvement in indoor air pollution after

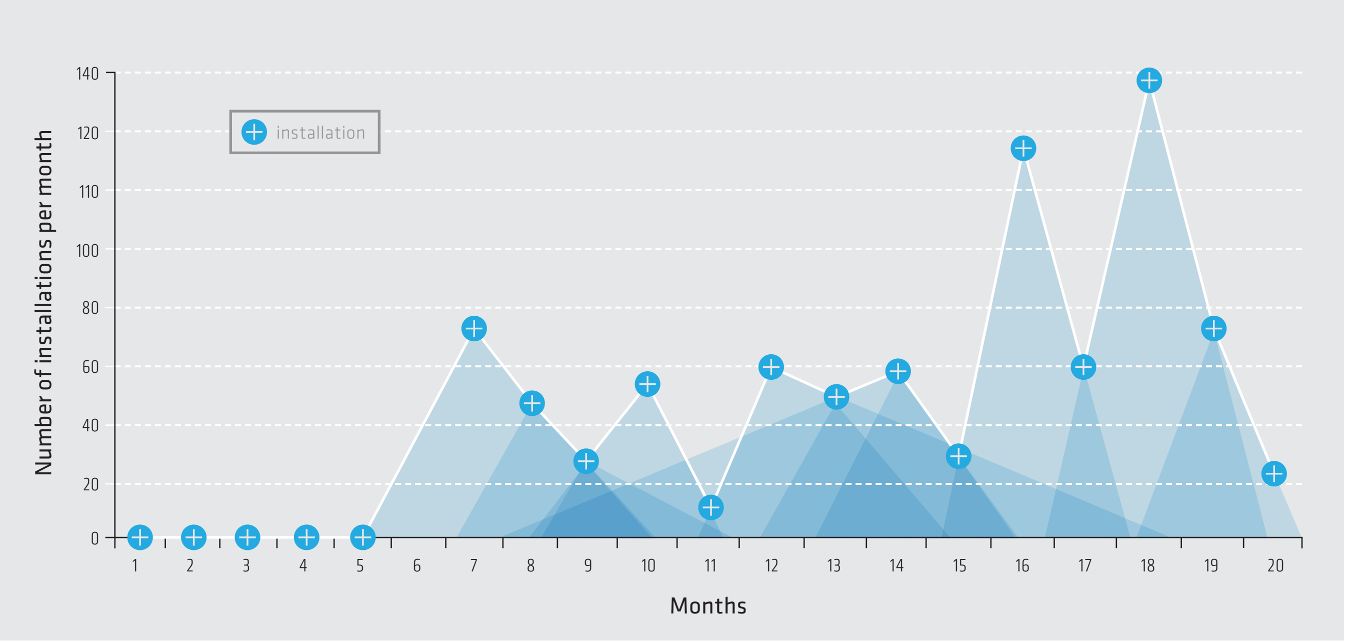


FIG 3: Number of smoke hoods installed per month

installation. The project monitored the levels of particulates and carbon monoxide over a 24-hour period using equipment placed inside the kitchen, 1.3 m away from and 1.3 m above the stove, ideally attached to the kitchen wall. For particulate matter, the main tool adopted was a gravimetric measure, where PM 2.5 particles were collected on a filter and weighed. GasBadgePro single gas monitors were used to measure levels of carbon monoxide.

Continuous measurements were taken to account for variations in total emissions throughout the day. The results showed that levels of IAP were found to be significantly reduced after intervention with the installation of smoke hoods (see Table 1) reducing levels of both particulates and carbon monoxide. Specifically:

- PM2.5 (24 hours average) 753 µg/m3 with traditional stove and 118 µg/m3 after smoke hood intervention.
- Carbon monoxide (24 hours average) 32.13 ppm with traditional stove and 2.25 ppm after smoke hood intervention.

OUTCOMES

Following the installation of smoke hoods, user households experienced a drastic reduction in smoke levels inside the kitchen. The IAP survey results show that there was a reduction of IAP by about 82 percent after intervention. Installation of smoke hoods in 834 households contributed to improved respiratory health of approximately 1,670 women and children in the project areas. Within a few months, users noticed improvements in their health and in particular a reduction of respiratory problems in children, with less frequent headaches and eye problems. Cleanliness is another benefit of the smoke hoods noted by users.

An outcome of the project's education campaign is that more than 55,000 members of the rural population are now aware of the dangers of IAP and how to combat it. In addition, it was noted that due to increased awareness, a few households have also started to look for other low-cost options for cooking, such as mud improved stoves.

There have been some positive add-on outcomes that don't directly relate to the improvement in indoor air quality. The rural population in the project community is now better educated on the provision of revolving funds and microfinancing. Instead of subsidies, soft loans were provided to customers to buy and install smoke hoods through local cooperatives. The project provided seed money as a grant to local cooperatives to run the revolving funds and provide capacity-building training to local cooperatives so that they could manage the funds. Reports indicate that the

A few households have also started to look for other low-cost options for cooking, such as mud improved stoves.

local cooperatives in the different villages are running the revolving fund satisfactorily, while fund mobilization is good and repayment rates are acceptable.

The nine local cooperatives involved in the scaling-up of indoor smoke-alleviating technologies are now able to work with a range of technologies which contribute to improving indoor air quality. Additional benefits include an increase in cooperative membership and an increase in knowledge of management skills, which has improved overall performance, including developing connections with various district stakeholders.

Of the 50 local artisans initially trained to fabricate and install smoke hoods, 23 have adopted smoke hoods supply businesses, with the hope that these manufacturers will establish or expand on smoke hood manufacturing workshops. And a market-based institutional delivery system was established to ensure quality and a continuous supply of smoke hoods. Local quality control mechanisms have been established to ensure high quality is maintained via warrantee cards.

SCALING-UP, REPLICATION, AND FUTURE DIRECTIONS

Since the smoke hoods have a long lifespan, the need for manufacturers to install them will gradually diminish over time, as many of those trained to do installations are restricted by the physical distance between themselves and new markets. A solution from Practical Action is to manufacture the smoke hoods in a central workshop and train local builders to assemble "flat-pack" versions of the hoods. This would allow less skilled people to install the hoods wherever they might be needed, but not leave the original manufacturers unemployed once all the villagers had them in their homes, as the manufacturers would have smoke-hood construction as part of a set of skills rather than just one specific skill.

One issue with scaling up the project is that since smoke hoods are not stoves, it has proven difficult to raise their profile within the international arena and convey the fact that a smoke hood plus an improved stove can be a very effective combination, or that a smoke hood on its own can contribute to improved indoor air quality. The name has recently been changed to "hoodstoves" in an attempt to define the technology in a single word, but the challenge of raising their profile is ongoing. ⊗

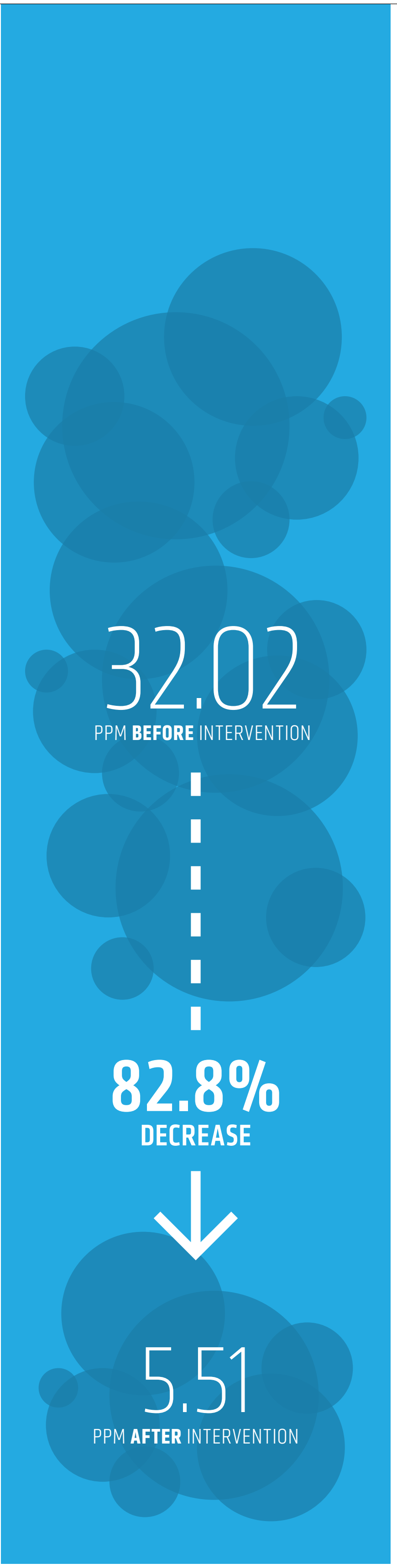


TABLE 1: Indoor carbon monoxide (ppm) measurements averaged over 24 hours

LESSONS LEARNED

- Cooking technologies need to fit local socio-cultural, economic and cooking needs in order for them to be accepted.
- Designs need to be simple enough to be manufactured locally.
- Working with early adopters is very important in creating demand. Installing smoke hoods in community leaders' homes provided an opportunity for other residents to observe the benefits of the hoods. This in turn triggered an increase in demand of the hoods.
- Mobilization of female community health volunteers was very helpful in disseminating messages across rural communities.
- Coordination with local development organizations was vital to the success of this project.
- Integrated actions involving public-private partnerships are required for the scaling-up of clean energy technologies, including microfinancing models, innovative social marketing, local manufacturing, and strong supply chains.
- Working with a community on tackling a problem and being willing to test different ideas makes it much more likely that the community will adopt the technology, as long as the technology addresses the communities' needs in a way that's agreeable to them. It is their needs, their choices, their homes, their money — it has to be their solution.

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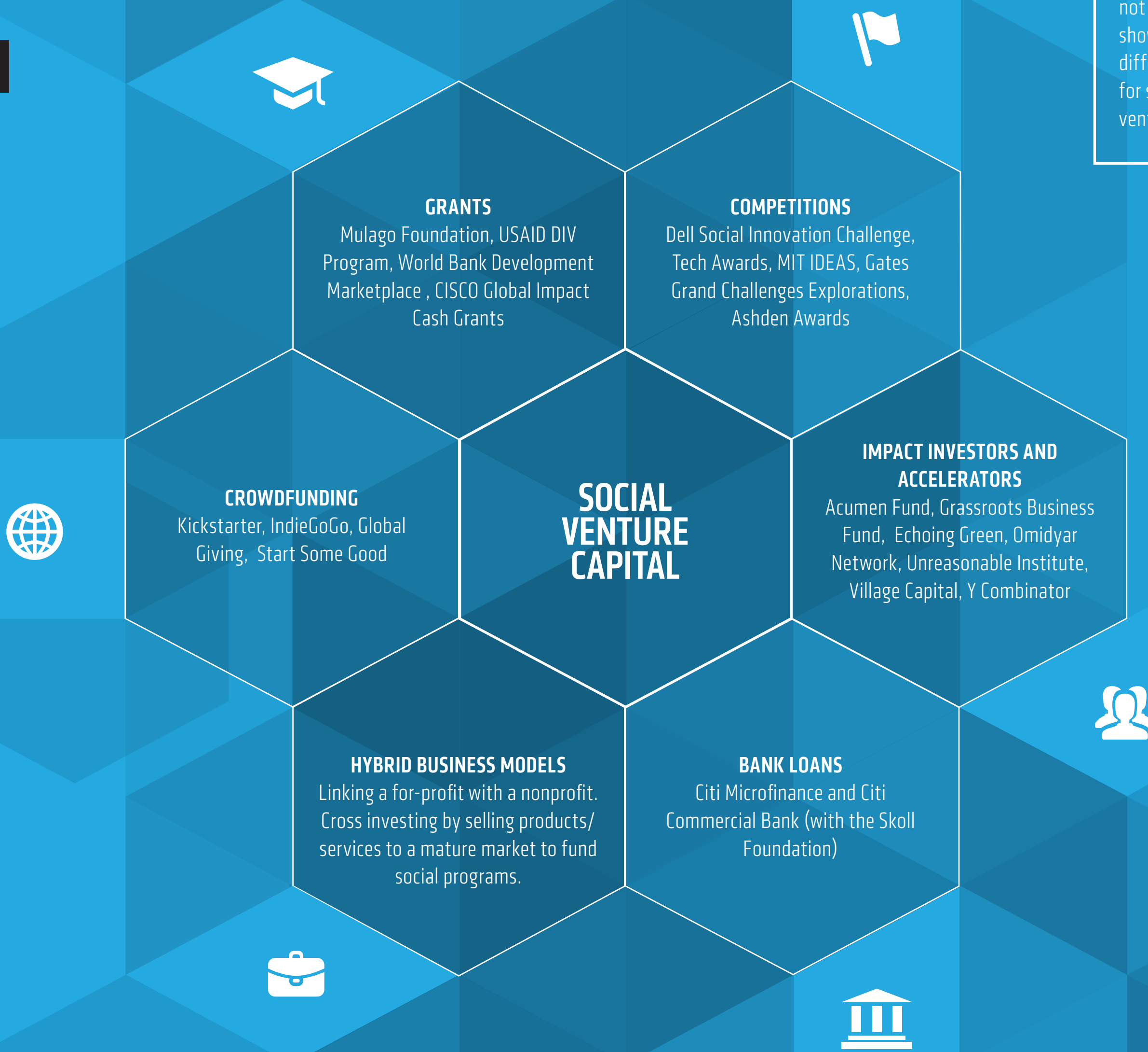
The pathways for funding and the organizations involved in funding social innovators are varied. The diagram, though not comprehensive, shows some of the different mechanisms for securing social venture capital.



SOCIAL INNOVATORS NEED MONEY, AND FUNDERS WANT TO GIVE IT TO THEM.

SO WHY IS IT SO HARD TO GET EVERYONE ON THE SAME PAGE?

BY ADRIENNE DAY

In 1961, in a blitz of New Frontier-era optimism, President John F. Kennedy established the Peace Corp and, eight months later, the U.S. Agency for International Development (USAID). At the time, direct government aid represented around 85 percent of all of the capital flowing to the developing world.

Fifty years later, this sector looks very different. According to the *National Journal*, direct government assistance now represents just one-tenth of capital entering developing countries. Making up the difference are remittences, philanthropic initiatives and private business investments, among other new funding models predicated on a fusion of different theories, aided and abetted by the advent of the Internet and the rise of international social entrepreneurship.

USAID's Development Innovation Ventures (DIV), founded in 2010 by USAID Chief Innovation Officer Maura O'Neill and Harvard Economist Michael Kremer, relies on one such "fusion" funding model. DIV is patterned after Silicon Valley's high-tech, high-risk, big-payoff (if you're lucky) model, combining methods from venture capital and academia to create a model for sourcing cost-effective development solutions. Where Silicon Valley and DIV diverge is after they reach the market: if your metric for success is not necessarily financial, how do you prove that what you're doing is actually creating impact?

This is the multibillion-dollar question being bounced around the social-entrepreneurship sector, and attempting to answer it is to address the myriad pain points on both sides of the equation. On one side are funders with limited time to review endless reams of proposals and limited resources to ensure that what works in theory will also work on the ground. On the other are the grantees who gripe about, among other things, high administrative costs; decreasing pools of grant money; a lack of partnerships for feedback on product feasibility; the longterm elbow-grease-fueled work involved with much in-field testing and evaluation; the outsourcing of larger projects to inept companies with brand recognition; and a gap in early-stage seed financing.

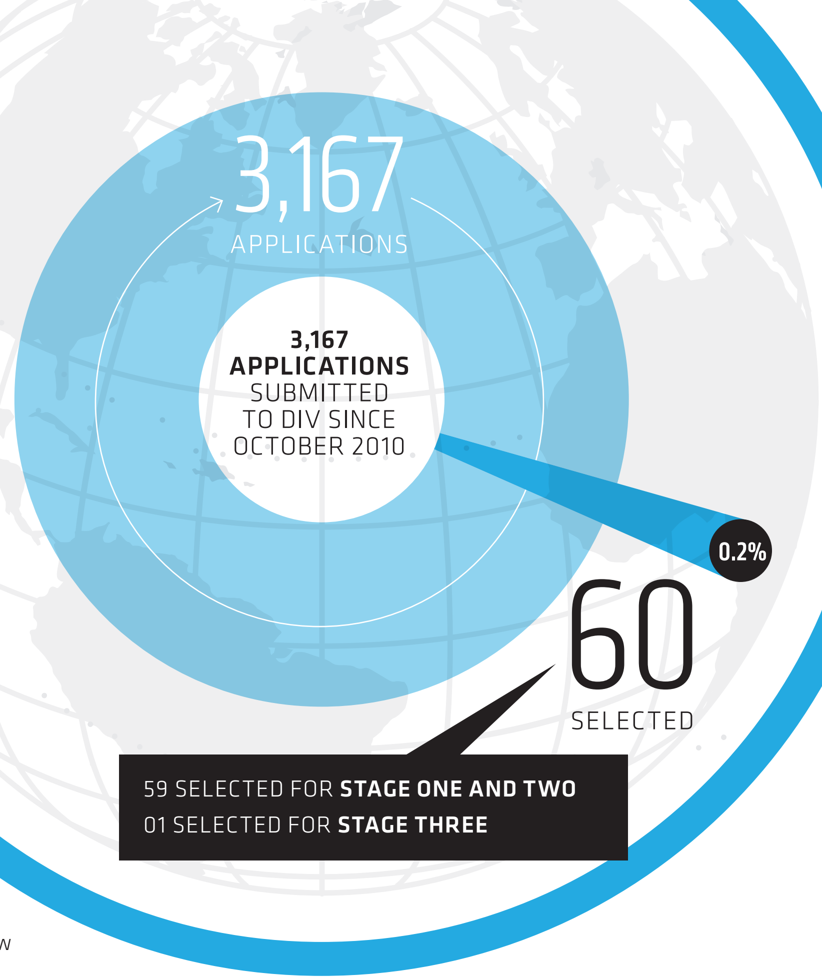
Mulago Foundation managing director Kevin Starr agrees with this last point, though he cites the for-profit Y Combinator and nonprofits Unreasonable Institute and Echoing Green, as well as Mulago, as examples of organizations that fund early-stage work. "There are a fair number of organizations that take people early on, but it's not very well organized and there's not enough of them," he says. But Starr thinks the real problem begins after the seed money is gone. "It's a classic situation I've seen time and time again, where [the grantee] gets some seed funding from their own savings, or their family or friends, or from an angel investor, then they start developing their idea and it looks promising, but then they run out of money before they're ready for prime time," he says. "You need to overestimate what you need, think about that next level and start lining it up. If you don't line it up [early] you're probably going to fail."

For agencies like USAID DIV, the answer to the question of "how do we know what we're doing is working?" lies in randomized controlled trials. "Sixty-eight percent of our grantees conduct randomized controlled trials, so [ideally] it's a combination of using that methodology to really test whether or not things are having the right outcome, and also measuring end goals or something highly connected to end goals," says Jeffrey Brown, USAID DIV's Division Chief. "Not just, 'were more people trained?' but did they really learn things, were their behaviors still changed a year later?"

DIV funds projects at three tiers, or stages. At the first stage, an organization is expected to establish proof of concept and innovation, and funding is generally capped at $100,000. During stage two, the organization is expected to evaluate solution at scale with rigorous impact testing, with funding up to $1 million. And during stage three, with criteria for stages one and two already met, an organization is expected to transition

> "You can improve a village's crop productivity, but how can you export products if their road is in shambles?"

their program to widespread adoption, reaching millions of people within 10 years, with up to $100 million in funding. The reason for the three-tier system is to weed out weak projects before they turn into the sort of boondoggles that traditional aid organizations are often accused of funding. "We expect that not all of our projects will succeed—that's why we initially go in at the 100K level," says Brown. "We think it's realistic that some of our projects will [work]. If they don't, we find out quickly and cheaply." The DIV application process is twofold: interested parties first submit a five-page letter of interest to DIV. DIV then selects the most promising of those letters and invites those organizations to submit full applications, each of which can run a total of 50 pages in length. To date, DIV has received 3,167 full applications and they've invested in around 60 of them in 24 countries around the world, with more in the pipeline. All projects save one are at the stage one and stage two levels, with a small majority clustered at



stage one. Any organization can apply at any tier, and the process at each tier is the same. Applicants can expect the entire process to take roughly six months, from the time they submit the letter of interest to the time they get funding. DIV offers feedback at both application stages, though they offer more detailed feedback after the full application has been submitted.

Starr has a very different philosophy when it comes to grant-giving. He credits USAID with trying "something cool" with DIV, though he's lukewarm on the DIV approach. "To date, USAID [doesn't] know how to invest for success," Starr says. Regarding DIV, he says, "Good ideas should get funded, and the idea that there are only [a few] of those doesn't make any sense to me, and I think processes like DIV's that attract a ton of applicants really wastes people's time. If there are a thousand applicants and they each spent 20 hours applying, that's 20,000 hours wasted."

"I think processes like DIV's that attract a ton of applicants really wastes people's time."

Starr's—and the Mulago Foundation's—philosophy is deceptively simple. For one, they look for people to fund instead of accepting proposals. "I hate to say no, and you say no a lot less if you're looking rather than just being passive and responding," Starr says. Mulago funds on the basis on three things: a problem that clearly fits their mission; a scaleable solution; and an organization that they think can deliver. Starr also believes that an organization worth funding should be able to channel its vision into an eight-word mission statement. "What are you setting out to do? Are you saving kids' lives, are you getting Zambian farmers out of poverty? The mission statement isn't supposed to be exciting. It's not branding." In other words, loose verbiage dotted with words like "sustainability" and "empowerment" often indicates that the organization's goals are muddy. "A good eight-word mission statement helps guide more established organizations through the necessary iterative process of re-design," Starr says. "For a startup, it's a opportunity to evolve their big idea without getting pulled off track by their business model, the demands of funders, or the latest shiny object they found by the side of the road."

Daniel Ignacio Garcia founded the Emergent Engineers startup a year ago, and has applied for aid from multiple organizations with lackluster results. He sees flaws with both traditional World Bank-style funding and DIV's three-tiered model. For him, the real problem is a "missing line item" in programs that don't factor in basic infrastructure issues, something his startup targets, fixing rural roads and irrigation systems and the like. "You can improve a village's crop productivity, but how can you export products if their road is in shambles?" he says. Regarding DIV, he says, "Voluminous administrative [costs] curtail or strangle the funding that comes into these organizations—the amount of paperwork involved is too much for a small firm to handle."

Peter Haas, executive director of small business incubator at the Appropriate Infrastructure Development Group, agrees, but sees all the paperwork as a necessary evil. "It's 60 percent paperwork and 40 percent action, but that's the way it is with all grants." Haas sees a bigger flaw with the "big ideas" dreamed up by aspiring social entrepreneurs: too much innovation, not enough implementation. "Many [social entrepreneurs] are not working continuously with the community," he says. "They design things that people don't want, so the project wins awards but then just sits on a university shelf somewhere. Starr agrees: "If people don't have a plan to implement when they innovate, it goes nowhere." ⊗

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